AN EXPERIMENTAL INVESTIGATION ON THE MECHANICAL PROPERTIES AND PERFORMANCE OF HYBRID FIBER REINFORCED CEMENT FREE CONCRETE

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Abstract: - *In this study, industrial by-product such as GGBS and Calcined kaolin will be used along with potassium hydroxide and potassium silicate activators to produce Hybrid fiber reinforced Cement free concrete. Jute and Coir fibres will be incorporated in the mix to improve the properties of the concrete. In this study cement is fully replaced by GGBS and Calcined kaolin is added in proportions 10%, 20%, 30% and 40% of GGBS and fibre dosage is varied in multiples of 0.25% by weight of Cementitious binder . Various tests will be conducted to determine Fresh and hardened properties of Hybrid fiber-reinforced geopolymer concrete .*

Key words: - Geopolymer concrete, hybrid fibre reinforced concrete, GGBS, OPC, Calcined kaolin

1. INTRODUCTION

For any construction practice concrete plays a key role. It is considered as second most widely utilized material on land. It mainly makes use of Ordinary Portland Cement (OPC) as its main source. The need of cement as construction product is rapidly and widely increasing at present situations. The Cement plants mainly emit Carbon Dioxide (CO_2) which is a greenhouse gas, this influences global warming in the clean atmosphere. When differentiated to various other greenhouse gases, CO_2 makes and contributes around 67-70% of global warming. The Cement production plants emits about 10-12% of greenhouse gas in the atmosphere. In order to prevent various and different types of environmental hazards mainly done by these cement plants other material as a binding source should be made use.

GPC are usually inorganic member with mineral molecular chains linked with Covalent bond. The major materials required for this concrete are alkaline activator liquid solutions and industrial by-products. GPC mainly undergo polymeric chemical reactions with the alkaline activator liquid solutions and industrial by-product and produce binding property. The Alumina and Silica mainly found in the industrial by-products majorly undergoes a unique reaction with the alkaline activator liquid solutions then imparts a better strength. The alkaline activator liquid solutions mainly used in the process of geo-polymerization are majorly the combined combination of Sodium or Potassium Silicate and Hydroxide.

GPC majorly reacts and interacts chemically with byproducts having Alumino-Silicate oxides (Si_2O_5, Al_2O_2) and with Alkali poly Silicates which usually gives raise to polymer Si – O – Al bonds. The mentioned equation below illustrates an illustration the degree of Poly condensation which mainly leads to the generation of Alkali Poly (Sialate-Siloxo).

1.2 AIM

The aim of this project is to study the suitability and performance of fibre reinforced geo polymer concrete produced by replacing Ordinary Portland Cement (OPC) with GGBS in the concrete production.

1.3 OBJECTIVES

- To study and evaluate the behaviour of fibre reinforced GPC in its fresh state with and without the addition of different fibres.
- To study and evaluate the behaviour of fibre reinforced GPC in its hardened state with and without the addition of different dosages of fibres.
- To ascertain the structural behaviour of the Geo-polymer concrete.
- To study the various durability properties of fibre reinforced GPC such as Water permeability, Sorptivity, Acid resistance, Rapid chloride penetration (RCP), Water absorption.
- To study the improvement in the properties of GPC when GGBS is partially replaced by Calcined kaolin.
- To produce an environmental friendly material for construction.
- To make use of industrial by product effectively (Calcined kaolin and GGBS).

1.4 SCOPE OF THE STUDY

The main scope of this current work is to evaluate the various properties of fiber reinforced GPC by varying the fiber dosage (Coir and Jute fibers) and also Calcined kaolin percentage in GGBS. The different fibers utilized in this work are coir and jute fibers in order to improve mechanical properties of GPC. The major scope of this project work is to study suitability and performance of fibre reinforced GPC which can be used as an alternative to OPC concrete.

2. MATERIALS AND METHODOLOGY

2.1 Materials required for preparing Hybrid Fibre Reinforced Geo-polymer concrete

- Ground Granulated Blast Furnace Slag (GGBS).
- Calcined kaolin. (CK)
- Potassium hydroxide.
- Potassium silicate solution.
- Aggregates.
    - Fine Aggregates
    - Coarse Aggregates
- Jute and Coir Fibres
- Water

2.1.1 Ground Granulated Blast Furnace Slag (GGBS)

GGBS is mainly taken inorganic non metallic product usually obtained during wrought iron or pig iron manufacturing which in blast furnace at $1400^{0}C$ to $1500^{0}C$. About 305 kg of slag is achieved from one tone of wrought iron. This molten steel by-product is then cooled by water and then grounded to less than 45 microns with a specific surface area of about $400m^2/kg$ – $600m^2/kg$. GGBS consists of Silicates of Calcium and other different forms and Aluminates of Calcium and other different forms.

Fig. 2.1: GGBS

Table.2.1 : Chemical and Oxide composition of GGBS obtained from Jindal Steel Works (provided by manufacturer)

Sl. No	Constituents	JSW GGBS Percentage content (%)
1	CaO	37.34
2	Al_2O_3	14.42
3	Fe_2O_3	1.11
4	SiO_2	37.73
5	MgO	8.71
6	MnO_2	0.02
7	Sulphide Sulphur	0.39
8	Loss On Ignition	1.41
9	Insoluble Residue	1.59
10	Glass Content	92

Table 2.2: Properties of GGBS.

Sl. No	Properties	Results
1	Colour	White
2	Specific gravity	2.73
3	Fineness by using 90µ sieve	6%

2.1.2 Calcined Kaolin

Calcined Kaolin is an anhydrous form of Aluminium Silicate usually formed by heating the more fine grain sized natural kaolin to greater temperatures in the kiln. The calcination majorly increases the whiteness and then the hardness improves the electrical properties. The particle size distribution of the Calcined kaolin is normally found to be finer and hence it leads concrete to achieve and attain more strength by filling up the major to minor voids in the concrete.
In the current work Calcined kaolin was obtained from the M/s Britex Enterprises, Delhi.

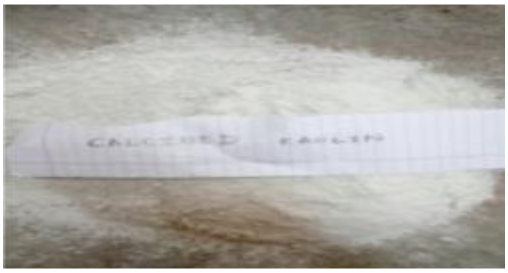

Figure 2.2: Calcined kaolin

2.1.3 Potassium hydroxide

Potassium hydroxide used in current project work is flakes. Commercial grade Potassium Hydroxide is effectively utilized to produce FRGPC. The purity of which is 92%. The major role of Potassium Hydroxide is to enhance strength of FRGPC.

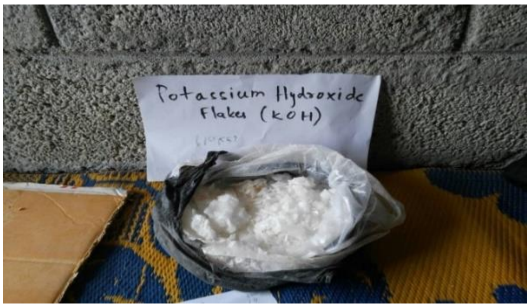

Fig. 2.3: Potassium hydroxide

2.1.4 Potassium silicate solution

Potassium Silicate is usually called as liquid glass. Potassium silicate is a whitish pale yellow semi gel. It has applications in waste water treatment plants, textile manufacturing industries and soaps producing industries.

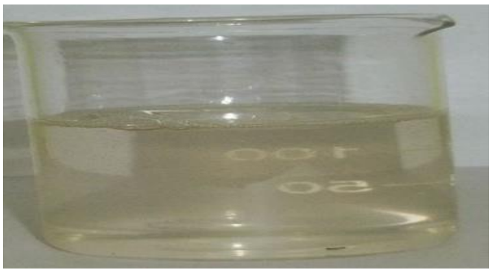

Fig.2.4: Potassium silicate

2.1.5 Jute and Coir Fibres

The introduction of fibres in concrete develops good tensile strength, which can be considered as a new type of binder which could combine OPC in bonding with the cement matrices. It is normally one of the cheapest fibres and also the strongest of all natural fibers.

Coir fibre used in the current project work was collected from the local market (commercially) which were then cut into tiny pieces of size 30mm.

Fig.2.5: Jute and Coir Fibres

2.1.6 Fine aggregates

M sand is utilized as fine aggregates to produce FRGPC. M sand used was totally surface dried and free from inorganic organic impurities content. Fine aggregates for this current work were tested as per Indian Standards. The sieve analysis of M sand was carried out as per the specifications provided in IS 383 – 1970.

Table.2.3: Properties of M sand (fine aggregates)

Sl. No	Tests	Results
1.	Fineness modulus	2.53
2.	Specific gravity	2.65

2.1.7 Coarse aggregates

The Coarse aggregates utilized in this present project work were 20 mm and 12.5 mm size aggregates.

Table.2.4: Properties of coarse aggregates (12.5 mm)

Sl. No	Tests	Results
1.	Fineness modulus	7.5
2.	Specific gravity	2.66

2.2 CONCRETE MIX DESIGN

This section majorly deals with experimental studies carried out on FRGPC. As there is no mix design for GPC absolute volume method is taken. In this work, GGBS is partially replaced by Calcined kaolin (0%, 10%, 20%, 30% and 40%). Then for the achieved optimum mix of GGBS and Calcined Kaolin, fibers are incorporated in varying percentages of 0.25%, 0.5% and 0.75% by weight of binder. Different tests such as Slump cone test, Compressive strength test, Split tensile strength, durability and water absorption tests have been conducted.

Table 2.5: Quantity of materials required for various geopolymer concrete mixes without the addition of fibres

Mix	CA in kg/m³	FA in kg/m³	GGBS in kg/m³	CK in kg/m³	KOH flakes	Mixing water for KOH	K_2SiO_3 Liquid	Extra H_2O W/GPS = 0.43
100% GGBS	1108.8	739.2	394.29	0	18.63	26.44	120.6	51.42
90 % GGBS + 10% CK	1108.8	739.2	354.86	39.43	18.63	26.44	120.6	51.42
80 % GGBS + 20% CK	1108.8	739.2	315.43	78.86	18.63	26.44	120.6	51.42
70% GGBS + 30% CK	1108.8	739.2	276	118.29	18.63	26.44	120.6	51.42
60% GGBS + 40% CK	1108.8	739.2	236.57	157.72	18.63	26.44	120.6	51.42

Table 2.6: Quantity of materials required for various geo-polymer concrete mixes with the addition of fibres

Mix	CA in kg/m³	FA in kg/m³	GGBS in kg/m³	CK in kg/m³	KOH flakes	Mixing water for KOH	K_2SiO_3 liquid	Hybrid fibres (jute and coir)	Extra H_2O W/GPS = 0.43
80 % GGBS + 20% CK + 0.25% fibres	1108.8	739.2	315.43	78.86	18.63	26.44	120.6	0.99	51.42
80% GGBS + 20% CK + 0.5% fibres	1108.8	739.2	315.43	78.86	18.63	26.44	120.6	1.56	51.42
80% GGBS + 20% CK + 0.75% fibres	1108.8	739.2	315.43	78.86	18.63	26.44	120.6	2.96	51.42

3 RESULTS AND DISCUSSIONS

3.1 WORKABILITY

Table 3.1: Slump test values without fibre

Mix No.	Binder content	Slump (mm)
M_1	100% GGBS	160
M_2	90% GGBS + 10% CK	190
M_3	80% GGBS + 20% CK	200
M_4	70% GGBS + 30% CK	220
M_5	60% GGBS + 40% CK	230

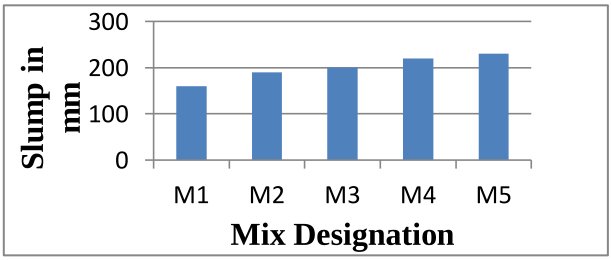

Fig 3.1: Slump test results without fibre

From the above results, it is clear that partial replacement of GGBS by Calcined kaolin up to 20% improves the workability of the mix. The micro fine nature of Calcined kaolin increases the slump value when the replacement percentage is increased. Partial replacement of Calcined kaolin up to 20% was found to be beneficial.

Table 3.2: Slump test values with fibres

Mix no.	Binder content	Slump (mm)
M_6	80% GGBS+ 20% CK+0.25% fibres	190
M_7	80% GGBS+ 20% CK+0.5% fibres	170
M_8	80% GGBS+ 20% CK+0.75% fibres	160

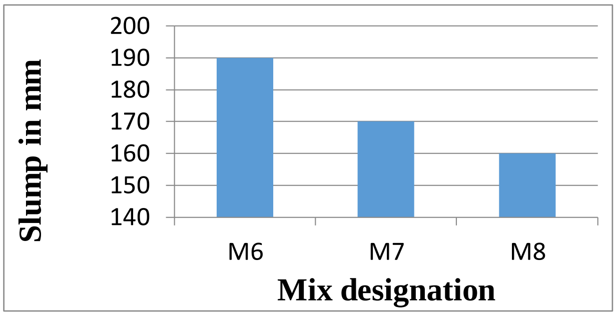

Fig 3.2: Slump test results with fibres

From the above results, it is clear that replacement of GGBS by Calcined kaolin improves the workability of mix. Partial replacement of Calcined kaolin up to 20% was found to be beneficial. IT is also observed that as the percentage of fibre increases the workability reduces because fibres require more cement paste to wrap around. If the cement paste is insufficient, then the slump or workability will be reduced.

3.2 COMPRESSIVE STRENGTH TEST RESULTS.

Table.3.3: The compressive strength test results of Geo-polymer Concrete without fibres.

Mix No.	Binder content	Compressive strength in MPa		
		7 Days	14 Days	28 Days
M_1	100% GGBS	43	45	45
M_2	90% GGBS + 10% CK	42	47	49
M_3	80% GGBS + 20% CK	45	51	52
M_4	70% GGBS + 30% CK	45	49	49
M_5	60% GGBS + 40% CK	40	41	41

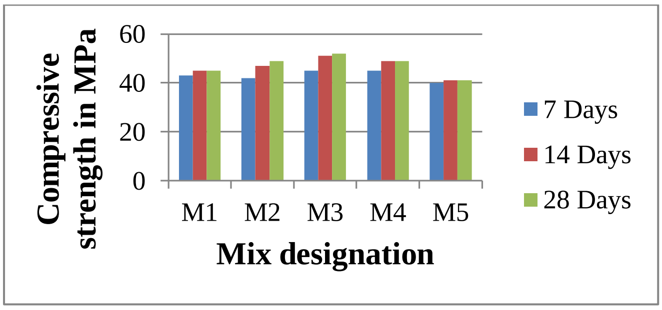

Fig 3.3: Compressive strength without fibre

Calcined kaolin being a supplementary cementious material, its fines and chemical properties has enhanced the strength of concrete. Calcined kaolin is normally found to be finer and hence it leads concrete to achieve more strength by filling up the voids in the concrete. Partial replacement percentage of CK up to 20% was found to be beneficial.

Table.3.4: The compressive strength test results of Hybrid fibres reinforced GPC with fibres

Mix No.	Binder content	Compressive strength in MPa		
		7 Days	14 Days	28 Days
M_6	80% GGBS + 20% CK + 0.25% fibres	47	55	56
M_7	80% GGBS + 20% CK + 0.5% fibres	48	57	59
M_8	80% GGBS + 20% CK + 0.75% fibres	51	58	60

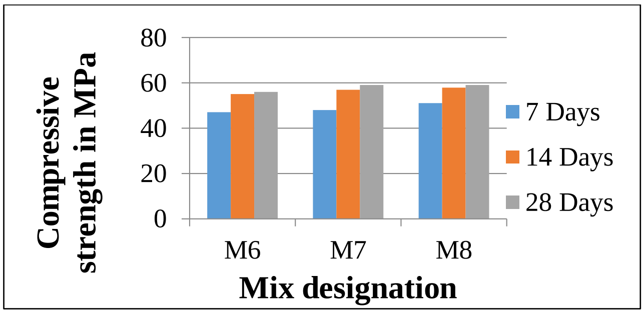

Fig 3.4: Compressive strength results with fibres

Increase in fibre dosage improved the compressive strength. This is because of high modulus of elasticity of fibres. The greater compressive strength is achieved for 80 % GGBS + 20 % CK + 0.75 % fibres, but for 0.75 % fibre content the workability reduces, hence 80 % GGBS + 20 % CK + 0.5 % fibres is considered as optimum.

3.3 SPLIT TENSILE STRENGTH TEST RESULTS.

Table.3.5: The Split tensile strength test results of Geo-polymer Concrete without fibre

Mix No.	Binder content	Split tensile strength in MPa		
		7 Days	14 Days	28 Days
M_1	100% GGBS	4.30	4.41	5.02
M_2	90% GGBS + 10% CK	4.48	4.63	5.11
M_3	80% GGBS + 20% CK	4.71	4.83	5.24
M_4	70% GGBS + 30% CK	4.56	4.95	4.84
M_5	60% GGBS + 40% CK	4.11	4.20	4.52

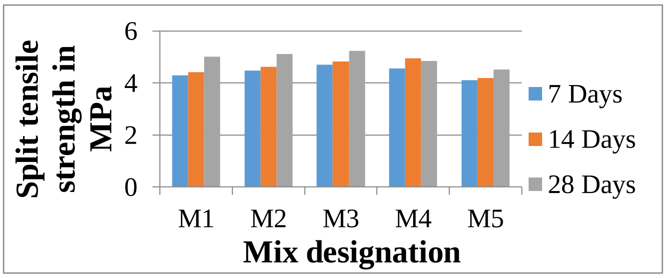

Fig 3.5: Split tensile strength results without fibre

Replacement of GGBS by CK increased the Split tensile strength. It is observed that 80 to 90% of 28 days compressive strength is achieved in 7 days for a optimum mix of 80% GGBS + 20% CK + 0.5% fibres. Potassium Hydroxide is mainly imparting the strength to FRGPC.

Table 3.6: The Split tensile strength test results of Hybrid fibres reinforced Geo-polymer Concrete withfibre

Mix No.	Binder content	Split tensile strength in MPa		
		7 Days	14 Days	28 Days
M_6	80% GGBS + 20% CK + 0.25% fibres	4.88	5.46	5.56
M_7	80% GGBS + 20% CK + 0.5% fibres	4.96	5.84	5.88
M_8	80% GGBS + 20% CK + 0.75% fibres	4.99	5.90	5.98

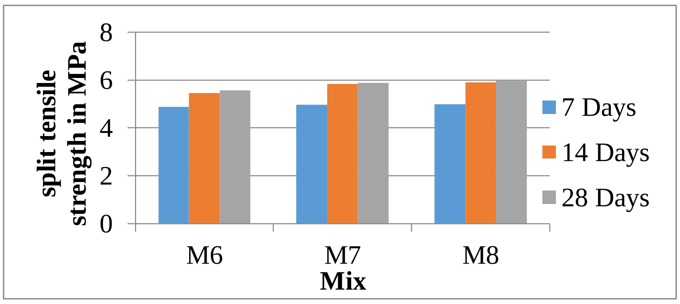

Fig 3.6: Split tensile strength results with fibre

Concrete is good in compression and weak in tension. The introduction of fibres in concrete develops good tensile strength. From above results, it can be concluded that Partial replacement of CK up to 20% + 0.5% of fibre addition gives good tensile strength.

3.4 WATER PERMEABILITY TEST RESULTS

The test is carried out on 150 mm× 150 mm× 150 mm FRGPC specimens after 28 days of curing in water. These specimens are usually subjected to 5 Bar pressure for 72 hours. After 72 hours the depth of water penetration is recorded using water penetrometer.

Table 3.7: Water permeability test results

Mix No.	Binder content	Depth of penetration (mm)
M_1	100% GGBS	10.06
M_7	80% GGBS + 20% CK + 0.5% fibre	7.11

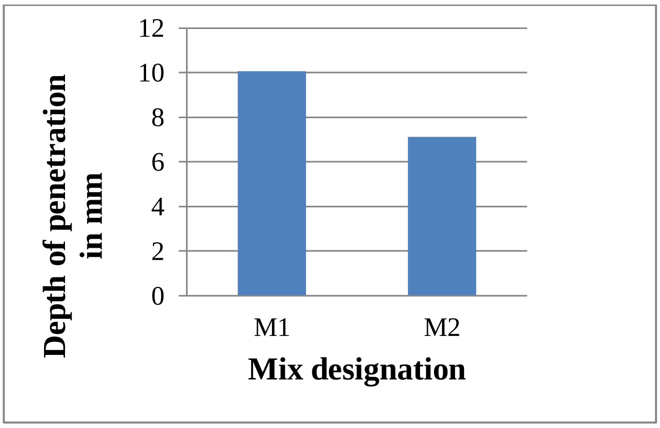

Fig 3.7: Water permeability test results

3.5 RAPID CHLORIDE PERMEABILITY TEST (RCPT)

The electrical conductance of FRGPC samples includes measuring the charges in coulombs to give a rapid result of its resistance to penetration of chloride ion. The RCPT test results are as follows.

Table 3.8: RCPT test results

Mix No.	Binder content	RCPT Values in Coulombs
M_1	100% GGBS	1211.3
M_7	80% GGBS + 20% CK + 0.5% fibres	798.2

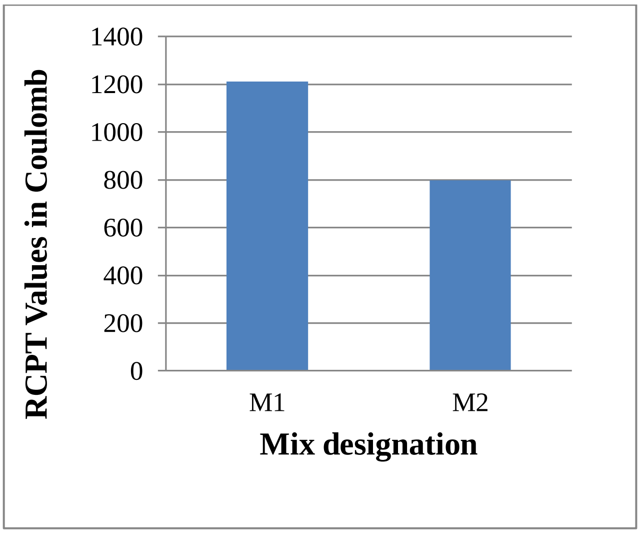

Fig 3.8: RCPT test results

3.6 ACID RESISTIVITY TEST

The loss in weight of FRGPC samples is the difference between the mass of sample before immersion and the mass of sample after immersion in acid. The test results of FRGPC after submerging the samples for 28 days is shown in the table below.

Table 3.9: Acid resistivity test results

Mix No.	Binder content	Weight before immersion (gms)	Weight after 28 days immersion (gms)	Loss in weight (gms)
M_1	100% GGBFS	8424	8228	196
M_7	80% GGBS + 20% CK + 0.5% fibres	8528	8391	137

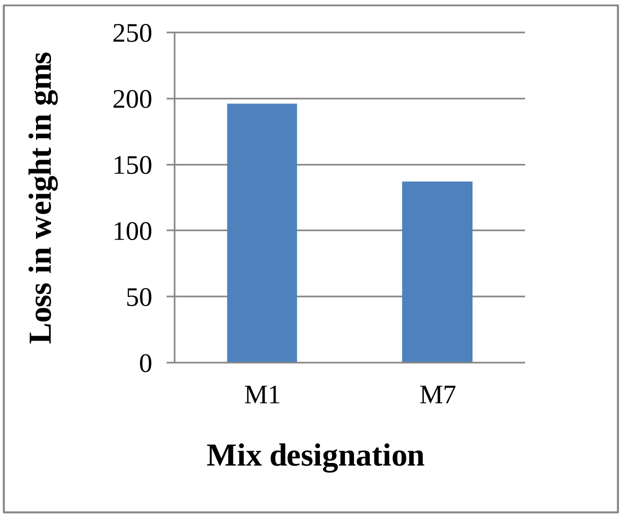

Fig 3.9: Acid resistivity test results

3.7 SORPTIVITY TEST

Table 3.10: Sorptivity test results

Mix No.	Binder content	Water absorbed by capillarity (kg)					
		15 min	30 min	1 hour	24 hours	48 hours	72 hours
M_1	100% GGBFS	0.00010	0.00020	0.00026	0.00038	0.00048	0.00058
M_7	80%GGBS + 20% CK + 0.5% fibres	0.00004	0.00012	0.00013	0.00031	0.00034	0.00041

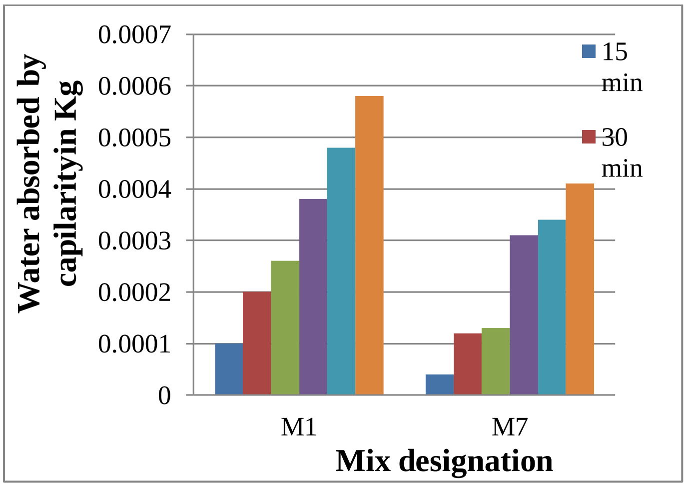

Fig 3.10: Sorptivity test results

Comparative durability studies were conducted on 100% GGBS mix and optimum mix obtained is 80% GGBS + 20% CK + 0.5% fibres. The durability test results showed that the mix with 80% GGBS + 20% CK + 0.5% fibres has better resistance to various Environmental effects and this is because combination of GGBS and CK has better polymerization reaction which resulted in the formation of a strong matrix compared to plain GGBS mix.

3.8 WATER ABSORPTION TEST

Table.3.11: Water Absorption Test Results of Geo-polymer Concrete without fibre

Mix No.	Binder content	24 HOUR Water (H_2O) Absorption			
		Dry weight of specimen (kg)	Density (kg/m³)	wet weight of specimen (kg)	Water absorption percentage (%)
M_1	100% GGBS	8.084	2395.26	8.093	0.111
M_2	90% GGBS +10% CK	7.981	2364.74	7.911	0.125
M_3	80% GGBS + 20% CK	8.059	2387.85	8.07	0.136
M_4	70% GGBS + 30% CK	7.909	2343.41	7.924	0.190
M_5	60% GGBS + 40% CK	8.022	2376.89	8.064	0.523

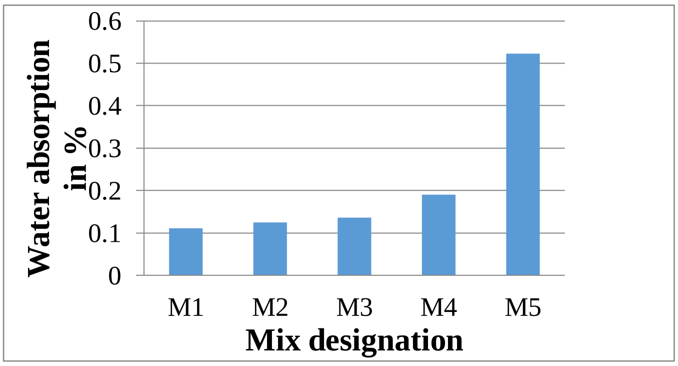

Fig 3.11: Water Absorption Test Results without fibre

Table 3.12: Water Absorption Test Results of Hybrid fibres reinforced Geo-polymer Concrete with fibre

Mix No.	Binder content	24 HOUR Water (H_2O) Absorption			
		Dry weight of specimen (kg)	Density (kg/m³)	wet weight of specimen (kg)	Water absorption percentage (%)
M_6	80% GGB + 20% CK + 0.25% fibres	8.059	2387.85	8.07	0.136
M_7	80% GGBS + 20% CK + 0.5% fibres	7.981	2364.74	7.911	0.125
M_8	80% GGBS+ 20% CK + 0.75% fibres	8.084	2395.26	8.093	0.111

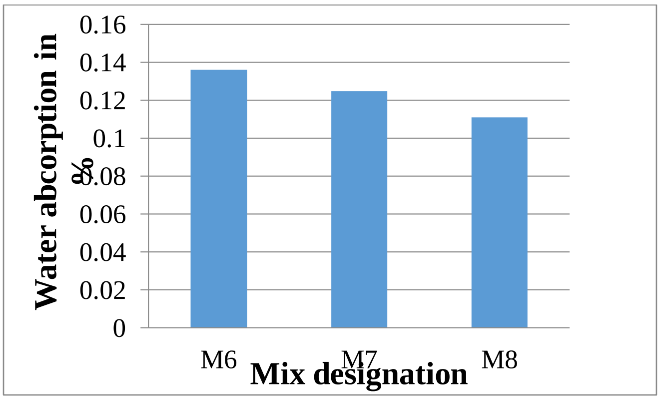

Fig 3.12: Water Absorption Test Results with fibre

From the above results, it is observed that the water absorption of FRGPC is very less because of micro fine nature of Calcined kaolin, which is used for the production of FRGPC.

4. CONCLUSIONS

- Increase in CK content improves the workability properties as CK is finer than GGBS which helps in filling up the voids which results in improving the concrete properties.
- Increase in CK content up to 20% and increase in fibre content improved the mechanical properties such as compressive strength and split tensile strength as uniformly distributed discrete fibres improves the load carrying capacity of mix.
- The optimum mix for FRGPC is when the CK content is 20% and GGBS content 80% and 0.5% fibres as this mix had better workability and improved compressive strength and split tensile strength.
- The durability tests (Water permeability, RCPT, Acid resistance and Sorptivity) showed good results compared to normal concrete as combination of GGBS and CK has better polymerization reaction which results in strong matrix compared to 100% GGBS mix.
- It is observed that FRGPC sets gradually at room temperature with the addition of GGBS which is mainly due to high degree of reaction of GGBS with Sodium Hydroxide and Sodium Silicate and thus ambient curing conditions can be adopted. The compressive strength test results for 7 days are 80-95% of its 28 days strength.
- The density of FRGPC is same as the density of normal conventional concrete.
- By the complete elimination of OPC the greenhouse gas emission to the atmosphere can be reduced. Thus this reduction in greenhouse gas mainly reduces the global warming caused by cement industries.

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