REHABILITATION OF REINFORCED GEOPOLYMER CONCRETE BEAM

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Abstract - *The aim and scope of this project is to prepare eco-friendly geopolymer RC beam with 100% replacement of cement along with wrapping of oven dried fibre mat with number of layers and achieving the required target mean flexural strength of conventional concrete. This project comprises material testing of ingredients for geopolymer concrete such as Low Calcium Fly Ash, Metakaolin, Lime, Alkaline liquids (sodium silicate+sodium hydroxide), Fine Aggregate (natural sand) and coarse aggregates.At first, The conventional Reinforced Concrete beam of grade M20 is casted and testing of conventional RC beam for finding the load carrying capacity and flexural strength was done after 28 days curing period. The report represents the comprehensive summary of extensive studies conducted on fly ash based geopolymer concrete. Test data are used to identify the effects of salient factors that influence the properties of geopolymer concrete in the fresh and hardened states. These results are utilized to propose sample for the design of geopolymer concrete mixtures.*

Key Words: **Low Calcium Fly Ash, Metakaolin, Lime, Alkaline liquids (sodium silicate+sodium hydroxide)**

1. INTRODUCTION

Concrete is the most abundant manmade material in the world. One of the main ingredients in a normal concrete mixture is Portland cement. However, the production of cement is responsible for approximately 5% of the world's carbon dioxide emissions. Among the Green house gases Carbon dioxide is the one which contributes about 65% for climatic change in the environment. In order to create a more sustainable world, engineers and scientists must develop and put into use a greener building material. This is unacceptable in a world where sustainable and green building has become a major issue. This brings up a very good question: Is there a cleaner, more efficient, more reliable, and even stronger substitute to the concrete that is currently used? The answer is geopolymer concrete.

1.1 GEOPOLYMER CONCRETE

Geopolymer concrete does not use Portland cement; it uses a highly abundant material called fly ash. Fly ash is a waste by product of thermal power plant with high fineness (> OPC) which produces an impermeable geopolymer concrete. Geopolymer concrete is also much more durable that ordinary concrete due to its resistance to corrosion. It is also much stronger than ordinary concrete.There are two main constituents of geopolymers, namely the source materials and the alkaline liquids. The source materials for geopolymers based on alumina-silicate should be rich in silicon (Si) and aluminium (Al). These could be natural minerals such as kaolinite, clays, etc. Alternatively, by-product materials such as fly ash, silica fume, slag, rice-husk ash, red mud, etc could be used as source materials. The choice of the source materials for making geopolymers depends on factors such as availability, cost, type of application, and specific demand of the end users. The alkaline liquids are from soluble alkali metals that are usually sodium or potassium based. The most common alkaline liquid used in geopolymerisation is a combination of sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate or potassium silicate. Low-calcium (ASTM Class F) fly ash is preferred as a source material than high-calcium (ASTM Class C) fly ash. Since class F fly ash is preferred over class C due to a lower percentage of calcium. Presence of calcium in elevated levels could hinder the polymerization reaction and leads to flash set due to the formation of calcium hydrate products.

1.2 COMPOSITION AND CREATION

Geopolymer concrete is made of up multiple ingredients. Like normal concrete, about 75%-80% of the mass is made of coarse and fine aggregates. An example of coarse aggregate is crushed stone or gravel and an example of fine aggregate is sand. Chemical admixtures such as air entrainers or super plasticizers can be added to the concrete mixture so that its qualities can be adjusted to meet the needs of the project. Air entrainers add air bubbles into the mixture and super plasticizers reduce the amount of water in the mixture and allow it to be much more workable. However, while ordinary concrete uses cement to bind the aggregates together, geopolymer concrete mixtures use a geopolymer paste. Geopolymer paste is created by combining fly ash, which contains silicon and aluminum, with a sodium hydroxide and sodium silicate solution. This is also known as water glass. The resulting reaction starts the process of geopolymerization which leads to the creation of a geopolymer.

1.3 APPLICATION OF GEOPOLYMER CONCRETE

- Pre-cast concrete products: Structural and non-structural members for building systems and bridge structures, Railway sleepers, Electric power poles, Sewer system, and other products for infrastructure.
- Waste containment/encapsulation.
- Road bases, marine structures.
- Geopolymer resins and binders.
- Fire-resistant materials, thermal insulation, foams.

2. MATERIALS USED

2.1 FLYASH

FLY ASH is consumed of the non-combustible mineral portion of coal. When coal is consumed in a power plant, it is first ground to the fineness of powder. Blown into the power plant's boiler, the carbon is consumed leaving molten particles rich in silica, alumina and calcium. These particles solidify as microscopic, glassy spheres that are collected from the power plant's exhaust before they can "Fly" away- hence the product's name: FLY ASH. Geopolymer concrete generally requires the use of Class F fly ash

Table -1: Physical / Mechanical properties of fly ash:

S.No	Properties	Test Result Range	Specified Requirements As Per Is:3821 (Part - I) -1966
1.	Fineness–Specific surface by Blainess permeability method.	3267 – 6842 cm²	3200 cm² minimum
2.	Reactivity		
	a. Lime reactivity strength of kg/cm²	47.4 – 83.4 kg/cm²	40 kg / cm² minimum
	b. Compressive strength of cement mortar cubes at the age of 28 days	80.4 – 94.5 kg/cm²	Not less than 80 % of the strength of corresponding plain cement mortar cubes
3.	Soundness by autoclave	0.1 – 0.2 cm	0.15 cm maximum
		0.02 – 0.07 cm	0.8 cm maximum

2.2 ALKALINE LIQUIDS

The most common alkaline liquid used in geopolymerization is a combination of sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate or potassium silicate to form alkaline solution($NaOH + Na_2Sio_3$).

2.3 NATURAL SAND

Sand (>0.07mm) is used as a fine aggregate in mortar and concrete.

2.4 FINE AGGREGATE

Natural sand of size between 75µm - 4.75mm is used as fine aggregate.

2.5 SUPER PLASTICIZER (CONPLAST SP-430)

Super plasticizers, also known as high range water reducers, are chemical admixtures used where well-dispersed particle suspension is required. The strength of concrete increases when the water to cement ratio decreases.

2.6 LIME

In order to overcome the creep effect in geopolymer concrete beam we introduce lime for curing in ambient temperature with a percentage of 5% by the weight of total fly ash.

2.7 METAKAOLIN

Metakaolin is a dehydroxylated form of the clay mineral kaolinite. Rocks that are rich in kaolinite are known as china clay or kaolin, traditionally used in the manufacture of porcelain. The particle size of metakaolin is smaller than cement particles, but not as fine as silica fume.

Table -2: Properties of Aggregates

Property	Coarse Aggregate		Fine Aggregate
	20 mm	12.5 mm	
Specific Gravity	2.60	2.60	2.58
Fineness modulus	6.55	6.55	4.165

3. MIX PROPORTION OF GEOPOLYMER CONCRETE

Density of G.P.C. = 2400 kg/m³
F.A. (30% of total aggregate) = 0.3×1848 = 555 kg/m³
C.A (70% of T.A) = 0.7× 1848 = 1293 kg/m³
Sodium silicate / sodium Hydroxide = 2.5 (assumed)

Fine aggregate + coarse aggregate = 77% of 2400 = 1848 kg/ m^3
2400 - Total aggregate = Fly ash + sodium Silicate + sodium Hydroxide (alkaline solution)
Alkaline Liquid/ fly ash = 0.4 (assumed)
SIZE OF BEAM 150 mm X 230 mm X 2100 mm.

Table -3: Material required for one beam

Materials	Quantity
Fly ash	25,71 Kg
metakaolin	2.86 Kg
Fine aggregate	40.20 Kg
Coarse aggregate	93.68 Kg
Sodium hydroxide	1090gm
Sodium silicate	(2.5 x 1090 gm + water)

4. MIXING PROCESS OF GEOPOLYMER CONCRETE

Chemical liquid reacts with the Si and Al atoms in the source material (for example, low-calcium fly ash). Gel formation (or polymerization), is assisted by applied heat, then Gel binds the loose coarse aggregate, fine aggregate, and un-reacted source material to give Geopolymer Concrete. Mix Sodium Hydroxide flakes and water in a designed proportion and mix sodium silicate paste and water in a designed proportion. Then, mix the above solutions and keep it for 24 hours. The above solution is mixed with fly ash, metakaolin and aggregates to get geopolymer concrete.


Fig -1: Sand+Fly Ash+Metakaolin Fig **-2**: Alkaline Solution

Fig -3: Geo Polymer Concrete Beam

5. REINFORCEMENT ON RC BEAM

Mild steel rods of 2 no's of 8mm diameter bars are provided at the bottom and 2 no's of 6mm diameter bars at the top with stirrups of 6mm diameter at 150mm spacing.

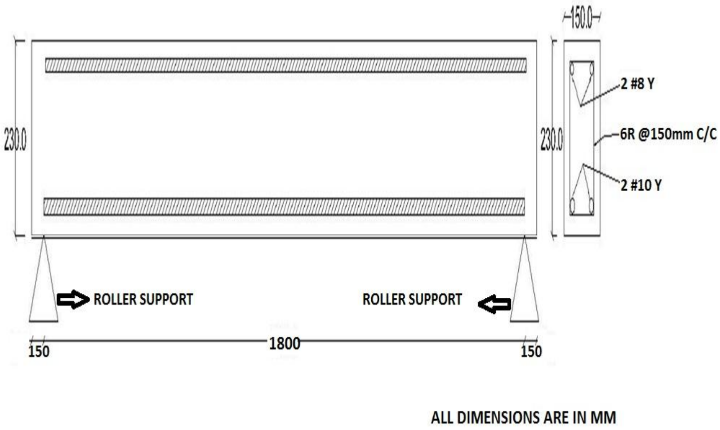

Fig -4: Reinforcement Details

6. SPECIMEN DETAILS

Table -4: Specimen Details on RC Beams

Beam	Dimensions (mm)	Soffit	Soffit + sides	Total
Controlled concrete	150 x 210 x 2100	1	1	2
Geo polymer concrete	150 x 210 x 2100	1	1	2

7. OVEN ROVEN GLASS FIBRE MAT

Oven roven glass fibres are used mainly in applications where they offer a unique combination of properties, such as high specific strength combined with toughness and creep resistance. The outstanding toughness of aramid is often the reason they are used over cheaper, stiffer or even stronger fibre.

7.1 CHARACTERISTICS

- Good resistance to abrasion.
- Good resistance to organic solvents.
- High strength in axial tension.
- No melting point, degradation starts from 500°C.
- Low flammability.
- Good fabric integrity at elevated.
- Sensitive to acids and salts.

8. EPOXY RESIN

Epoxy resins, also known as polyepoxides are a class of reactive prepolymers and polymers which contain epoxide groups. Epoxy resins may be reacted (cross-linked) either with themselves through catalytic homopolymerisation, or with a wide range of co-reactants including polyfunctional amines, acids (and acid anhydrides), phenols, alcohols, and thiols. These co-reactants are often referred to as hardeners or curatives, and the cross-linking reaction is commonly referred to as curing. Epoxy has a wide range of applications, including metal coatings, use in electronic and electrical components, high tension electrical insulators, fibre-reinforced plastic materials, and structural adhesives.

8.1 CURING ON EPOXY RESIN

Curing may be achieved by reacting an epoxy with itself (homopolymerisation) or by forming a copolymer with polyfunctional curatives or hardeners.In principle, any molecule containing reactive hydrogen may react with the epoxide groups of the epoxy resin. Common classes of hardeners for epoxy resins include amines, acids, acid anhydrides, phenols, alcohols and thiols. Relative reactivity (lowest first) is approximately in the order:

Phenol < Anhydride < Aromatic amine < Cycloaliphatic Amine < Aliphatic Amine < Thiol.

9. RESULT AND DISCUSSIONS

9.1 ULTIMATE LOAD AND ULTIMATE MOMENT

Ultimate load and Ultimate moment of Geopolymer and Conventional RC beam is determined for M20 grade. The beam mould of size 1500mm X 230mm X 2100mm is used. After curing of 28 days, all the RC beams are tested using universal testing machine of capacity 40 tones. The ultimate load taken by each beam (both conventional and Geopolymer concrete)

Table -5: Ultimate Load and Ultimate Moment

Beam	Beam ID	Ultimate load (KN)	Ultimate moment (KNm)
Conventional beam without fibre	CRCB -0	62.7	18.81
Conventional beam with fibre (soffit)	CRCB –S	65.3	19.59
Conventional beam with fibre (soffit + U)	CRCB –S+U	75.4	22.62
Geo polymer beam without fibre	GPRC -0	63.64	19.09
Geo polymer beam with fibre (soffit)	GPRC –S	67.17	20.151
Geo polymer beam with fibre (soffit + U)	GPRC–S+U	79.92	23.98

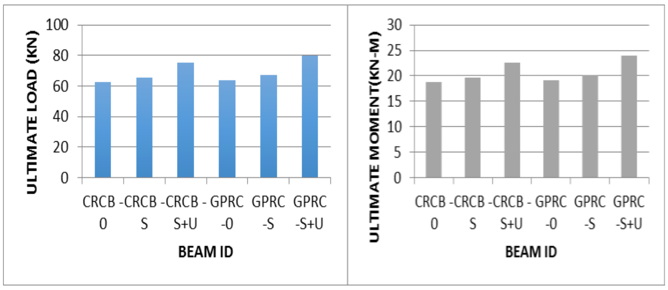

Chart -1: ultimate load and ultimate moment

This is evident that the yield load and yield moment of Conventional and Geopolymer RC beams with wrapping (soffit or U) improves the behavior of beam compared with conventional and Geopolymer RC beams without wrapping.

9.2 YIELD LOAD AND YIELD MOMENT

Yield load and Yield moment of Geopolymer and Conventional RC beam is determined for M20 grade. The Yield load taken by each beam (both conventional and Geopolymer concrete).

Table -6: Yield Load and Yield Moment

Beam	Beam ID	Yield load (KN)	Yield moment (KNm)
Conventional beam without fibre	CRCB -0	40	12
Conventional beam with fibre (soffit)	CRCB –S	42	12.6
Conventional beam with fibre (soffit + U)	CRCB –S+U	48	14.4
Geo polymer beam without fibre	GPRC -0	41	12.3
Geo polymer beam with fibre (soffit)	GPRC –S	43	12.9
Geo polymer beam with fibre (soffit + U)	GPRC–S+U	51.15	15.345

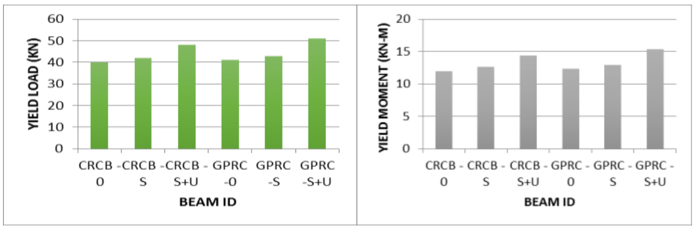

Chart -2: Yield Load and Yield Moment

This is evident that the yield load and yield moment of Conventional and Geopolymer RC beams with wrapping (soffit or U) improves the behavior of beam compared with conventional and Geopolymer RC beams without wrapping.

9.3 WORKING LOAD

Working load and Working moment of Geopolymer and Conventional RC beam is determined for M20 grade. The Working load taken by each beam (both conventional and Geopolymer concrete).

Table -6: Working Load

Beam	Beam ID	Working load (KN)
Conventional beam without fibre	CRCB -0	32.5
Conventional beam with fibre (soffit)	CRCB –S	35.75
Conventional beam with fibre (soffit + U)	CRCB –S+U	36.95
Geo polymer beam without fibre	GPRC -0	34
Geo polymer beam with fibre (soffit)	GPRC –S	36.27
Geo polymer beam with fibre (soffit + U)	GPRC–S+U	39.17

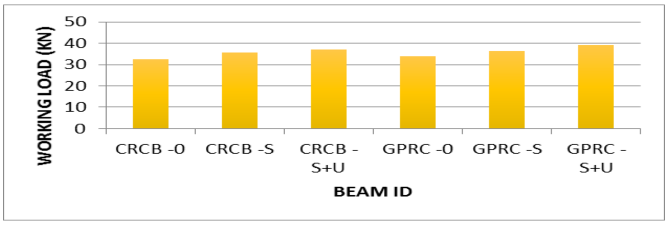

Chart -3: Working Load

This is evident that the Working load or Initial crack load of Conventional and Geopolymer RC beams with wrapping (soffit or U) improves the behavior of beam compared with conventional and Geopolymer RC beams without wrapping.

9.4 FLEXURAL STRENGTH

Flexural strength of Geopolymer and Conventional RC beam is determined for M20 grade. After 28 days curing, all the RC beams are tested for flexural strength using universal testing machine of capacity 40 tones. The maximum flexural strength taken by each beam (both conventional and geopolymer).

Table -7: Flexural Strength

Beam	Beam ID	Ultimate load (KN)	Flexural strength (N/mm^2)
Conventional beam without fibre	CRCB -0	62.7	14.2
Conventional beam with fibre (soffit)	CRCB –S	65.3	14.81
Conventional beam with fibre (soffit + U)	CRCB –S+U	75.4	17.10
Geo polymer beam without fibre	GPRC -0	63.64	14.43
Geo polymer beam with fibre (soffit)	GPRC –S	67.17	15.24
Geo polymer beam with fibre (soffit + U)	GPRC–S+U	79.92	18.13

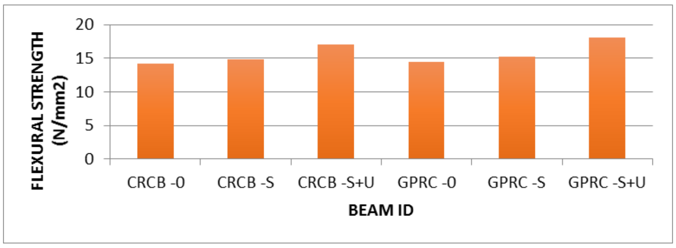

Chart -4: Flexural Strength

This it is evident that the flexural strength of Conventional and Geopolymer RC beams with wrapping (soffit and U) improves the behavior of beam compared with conventional and Geopolymer RC beams without wrapping.

9.5 DISPLACEMENT

Displacement of both conventional and Geopolymer RC beam with fiber (soffit and U) and without fiber are noted down. Displacement of all RC Beams are shown below,

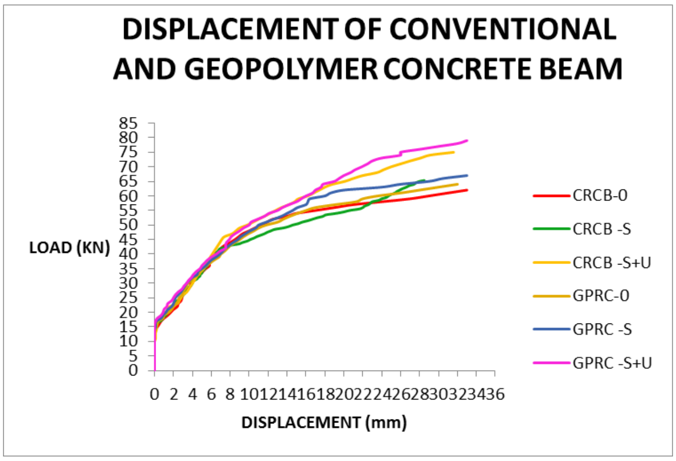

Chart -5: Displacement of RC Beams

9.6 MODE OF FAILURE

Table -8: Mode of Failure

Beam	Mode of failure
Conventional beam without fibre	Crushing of concrete
Conventional beam with fibre (soffit)	Delamination of fiber
Conventional beam with fibre (soffit + U)	Tearing of fiber
Geo polymer beam without fibre	Crushing of concrete
Geo polymer beam with fibre (soffit)	Delamination of fiber
Geo polymer beam with fibre (soffit + U)	Tearing of fiber

9.7 TESTING ON RC BEAMS

Fig -4: Testing Of Beam With Fibre (Soffit), (Soffit+ U) Wrapping

Fig -5: Crack Patterns Observed At Ultimate Load in Conventional Beam with Fiber at Soffit

9.8 ECONOMIC BENEFITS OF GEOPOLYMER CONCRETE

Heat cured low calcium fly ash based geo polymer concrete offers several economic benefits over Portland cement concrete. The price of one ton of fly ash is only a small fraction of the price of one ton of Portland cement. Therefore, after allowing the price of alkaline liquids needed to make the geo polymer concrete, the price of fly ash based geo polymer concrete is estimated to be about 10 to 30% cheaper than that of Portland cement concrete. In addition the appropriate usage of one ton of fly ash earns approximately one carbon-credit that has a redemption value of about 10 to 20 euros. Based on the information given in this report, one ton of low calcium fly ash can be utilized to manufacture approximately 2.5 cubic meters of high quality fly ash based geo polymer concrete, and hence earn monetary benefits through carbon trade. Furthermore, the very little drying shrinkage, the low creep, the excellent resistance to sulfate attack, and good acid resistance offered by the heat cured low calcium fly ash based geo polymer concrete may yield additional economic benefits when it is utilized in infrastructure applications.

10 CONCLUDING REMARKS

10.1 CONCLUSION

By introducing reinforcement and pasting the glass fibre mat we can achieve improved flexural strength.

- The load deflection characteristics of Conventional RC and Geopolymer RC beams are observed similar.
- Deflection of GPRC beam under ultimate load is less when compared to CRC beam while it is rehabilitated with glass fibre mat.

- Bonding strength between steel and geopolymer concrete shows very good performance.
- The load carrying capacity and flexural strength of GPRC beam is 1 - 2% more when compared to CRC beam.
- The load carrying capacity and flexural strength of GPRC beam with glass fiber at soffit gives 2 - 6% more when compared with CRC beam with glass fiber at soffit.
- The load carrying capacity and flexural strength of GPRC beam with glass fiber at soffit and sides gives 3 - 8% more when compared with CRC beam with glass fiber at soffit and sides.

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