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Compressive and split tensile strength behavior of geo polymer Concrete towards conventional concrete

Embadi Harish
Asst. Professor,
Samskruti College of Engg & Tech
embadi.harish1000@gmail.com

Janjirala Kiran Kumar
Asst. Professor,
Samskruti College of Engg Engg & Tech janjiralakiran123@gmail.com

Abstract-Concrete is the most common material for construction. The demand for concrete as a construction material leads to the increase of demand for Portland cement. Concrete is known as a significant contributor to the emission of green house gases. The cement industry is the second largest producer of the greenhouse gas. One of potential material to substitute for conventional concrete is geopolymer concrete. Geopolymer concrete is an inorganic alumino-silicate polymer synthesized from predominantly silicon, aluminium and by product materials such as fly ash, GGBS (ground granulated blast furnace slag).

Test specimens of 150×150×150 mm size were used for the study. 20-30% of Fly ash by the mass was replaced by GGBS. The variable used were percentage of steel fibre volume fraction viz. 0.0%, 0.5%, and 1%, and basalt fibre volume fraction viz. 0.0%, 0.15%,and 0.3%. The concentration of sodium hydroxide was 12Molar and 14 Molar in geopolymer concrete. For curing, temperature was fixed as 60^0 C for 24 hours. The geopolymer specimens were cured by using steam curing chamber. The specimens were cured after the rest period of three days. proper mixture proportion for geo-polymer concrete. The specimens were tested after the age of 7 days.

Key words: ***Geopolymer, Green concrete, Fibers,GGBS, Alkaline solution, flexural strength, Tensile strength and Compressive strength.***

I. INTRODUCTION:

1.1 GENERAL

The global use of concrete is second only to water. As the demand for concrete as a construction material leads to the increase of demand for Portland cement. Concrete is a mixture of Portland cement, aggregate, and water. Concrete is the most commonly used material in the world because of its outstanding strength, durability and availability. The worldwide consumption of concrete was estimated to be about 8.8 billion tons per year. Due to increase in infrastructure developments, the demand for concrete would increase in the future.

On the other hand, the climate change due to global warming has become a major concern. The global warming is caused by the emission of greenhouse gases, such as carbon dioxide ($CO2$), to the atmosphere by human activities. Among the greenhouse gases, $CO2$ contributes about 65% of global warming. The cement industry is held responsible for some of the $CO2$ emissions, because the production of one ton of Portland cement emits approximately one ton of $CO2$ into the atmosphere (Davidovits, 1994).

Several efforts are in progress to supplement the use of Portland cement in concrete in order to address the global warming issues. These include the utilization of supplementary cementing materials such as fly ash, granulated blast furnace slag, and alkaline solution to development of alternative binders to Portland cement

In this respect, the geopolymer technology shows considerable promise for application in concrete industry as an alternative binder to the Portland cement. In terms of global warming, the geopolymer technology could significantly reduce the CO_2 emission to the atmosphere caused by the cement industries.

1.2 GEOPOLYMER

Geopolymer are chains or networks of mineral molecules linked with co-valant bonds. Geopolymer concrete is the result of the reaction of materials containing alumina silicate with concentrated alkaline solution to produce an inorganic polymer binder. Geopolymer concrete is proven to have excellent engineering properties with reduced carbon foot print.

Geopolymer concrete is not only reduces the greenhouse gas emission but also it utilizes a large amount of industrial waste materials. 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 aluminum (Al). Geopolymer concrete can be manufactured by using the low-calcium (ASTM Class F) fly ash obtained from coal-burning power stations.

Alkaline solution is used as the biding material for geopolymer concrete. Alkaline solution is made using sodium hydroxide (NaOH) and sodium silicate (NaCl) solutions. Due to this attribute it is becoming an increasingly popular material for construction.

The term „geopolymer" was first introduced by Joseph Davidovits in 1978. He proposed that binder could be produced by a polymeric reaction of alkaline solution and the aluminium in source materials of geological origin or by-product materials such as fly ash. Because the chemical reaction take place in this case is a polymerization process, Davidovits coined the term „geopolymer" to the represent these binder.

In this work, low calcium (ASTM CLASS F) fly ash with GGBS (ground granulated blast furnace slag) based geopolymer is used as the binder. Fly ash GGBS based geopolymer paste binds the loose coarse aggregate, fine aggregate and other un-reacted materials to form the geopolymer concrete with or without presence of admixtures. The manufacture of geopolymer concrete is carried out using the usual concrete technology methods. As in case of OPC concrete, the aggregates occupy about 75-80% by mass, in geopolymer concrete.

1.3 FORMATION OF GEOPOLYMER

Geopolymers are members of the family of inorganic polymers formed by the reaction between an alkaline solution and an alumino-silicate source. The name geopolymer was formed by a French Professor Davidovits in 1978 to represent a broad range of materials characterized by networks of inorganic molecules. The geopolymers depend on thermally activated natural materials like Metakaolinite or industrial by products like fly ash or slag to provide a source of silicon (Si) and aluminum (Al). These silicon and Aluminium is dissolved in an alkaline activating solution and subsequently polymerizes into molecular chains and become the binder.

Professor B. Vijaya Rangan (2008), Curtin University, Australia, stated that, "the polymerization process involves a substantially fast chemical reaction under alkaline conditions on silicon-aluminum minerals that results in a three-dimensional

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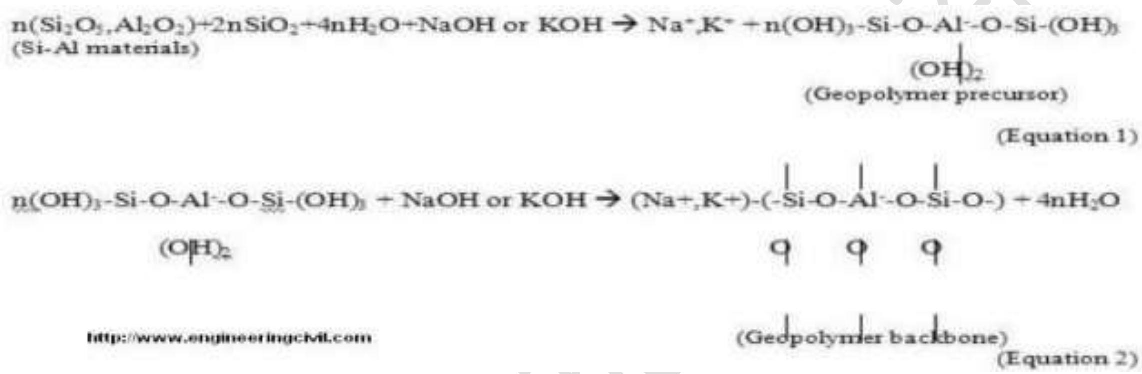
polymeric chain and ring structure". The ultimate structure of the geopolymer depends largely on the ratio of Si to Al (Si:Al), with the materials most often considered for use in transportation infrastructure typically having an Si:Al between 2 and 3.5.

The reaction of Fly Ash with an aqueous solution containing Sodium Hydroxide and Sodium Silicate in their mass ratio, results in a material with three dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds (Davidovits, 1994).

The schematic formation of geopolymer material can be shown as described by Equations (1) and (2) (Davidovits, 1994).



The last term in Equation 2 reveals that water is released during the chemical reaction that occurs in the formation of geopolymers. This water, expelled from the geopolymer matrix during the curing and further drying periods, leaves behind nano-pores in the matrix, which provide benefits to the performance of geopolymers

1.4 HYBRID FIBRE REINFORCED GOPOLYMER CONCRETE

Hybrid Fiber Reinforced Concrete (HFRC) is formed from a combination of different types of fibres which differ in material properties, remain bonded together when added in concrete and retain their identities and properties. The combining of fibers, often called hybridization.

Addition of fibres has an enormous potential in crack arresting and therefore fibre reinforced concrete has an enormous potential in crack arresting. As the fibres in to concrete structures have been effective in improving structural performance under gravity loads, improve the structural strength, ductility, as well as in increasing shear strength, energy absorption capacity , and damage tolerance in members subjected to several loading conditions. In this work Basalt fibre and Steel fibre with different volume fractions are used to made hybrid fibres.

1.5 SCOPE OF THE STUDY

The main scope of the project is described below:

- To reduce the greenhouse gas emission
- Use the industrial by-product materials such as fly ash, GGBS (which are base materials to make geopolymer concrete)
- The technology and the equipment currently used to manufacture OPC concrete were used to make the geopolymer concrete
- The concrete properties in shear like ultimate strength, load deflection relationship and energy absorption capacity are studied for the Fly ash and GGBS – based geopolymer reinforced concrete beams and compared with only Fly ash based geopolymer reinforced concrete beams.

1.6 OBJECTIVE OF THE STUDY

- To develop the proper mix proportion for geopolymer concrete and hybrid fibre reinforced geopolymer concrete.
- To study the shear behaviour of hybrid fibre reinforced geopolymer concrete beams made with Fly ash and GGBS.
- Comparison of results of hybrid fibre geopolymer concrete specimens with Fly ash base geopolymer concrete specimens.

II. LITERATURE REVIEW

2.1 STUDIES ON GEPOLYMER CONCRETE

a. Investigation carried out the Shear resistance of rectangular mortar beams reinforced with three combinations of steel fibers and conventional stirrups by **Narayanan et al. (1988).** The tests have also been designed to study the effect of partial replacement of cement by pulverized fuel ash (PFA). The experiments have demonstrated the advantages of combining steel fibers and stirrups for shear reinforcement. The partial replacement of cement by PFA results in improved workability and higher long term strengths. Based on the test observations, a rapid method of assessing the ultimate shear strength of reinforced concrete beams containing both stirrups and fibers as shear reinforcement is suggested. Good correlation has been obtained between observed test values and the predictions using the method suggested in this paper.

b. **Davidovits et al. (1994)** reported that in the production of geopolymer about less than 3/5 of energy is required and 80–90% less CO2 is generated than in the production of OPC. Thus, it is of great significance in environmental protection for the development and application of geopolymer cement.

The production of cement is increasing about 3% annually **(McCaffrey 2002).** The production of one ton of cement liberates about one ton of CO_2 to the atmosphere, as the result of de-carbonation of limestone in the kiln during manufacturing of cement and the combustion of fossil fuels (**Roy 1999).**

2.2 CONCLUSION OF LITERATURE REVIEW

- Production of geopolymer concrete is required less energy than the production of ordinary Portland cement concrete.
- The combination of fly ash (FA) and ground granulated blast-furnace slag (GGBS) is produces high-strength geopolymer concrete
- Low calcium Class F (ASTM) dry fly ash is more preferable for the geopolymer concrete due to rich in silicon and aluminium,
- Compressive strength of the geopolymer concrete is higher while comparing with ordinary Portland cement.
- Increasing in Fly ash fineness thus reduction in porosity.
- Addition of fibres to the geopolymer concrete will improve the mechanical properties of geopolymer concrete.
- The addition of basalt fiber can significantly improve deformation and energy absorption capacities of geopolymeric concrete.
- Use of steel fibres in different volume fraction in concrete can increase the ductility factor and load carrying capacity of specimens.
- Addition of fibres in Hybrid form with deferent material properties improved many of the engineering properties such as the first crack load, ultimate load and ductility factor of the composite.
- Steam curing is very effective for geopolymer concrete specimens.
- Strength of GPC increases if curing time is increased.
- Geopolymer concrete has high resistance to acid attacks.
- Geopolymer concrete withstand heat for long time.

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III. METHODOLOGY

The methodology adopted in this investigation involves experimental programme which consist of casting and testing of geopolymer concrete and hybrid fibre reinforced geopolymer concrete specimen.

The main stages involved in the project:

Collection of materials
⇩
Designing the mix proportion for concrete samples
⇩
Experimental investigations
⇩
Results and discussions
⇩
Conclusions

Table.3.1 Properties of Fly ash

SI. No.	Properties	Test results
1	Specific gravity	2.23
2	Fineness	224 m^2/kg
3	Consistency	45%
4	Silica (SiO_2)	52%
5	Calcium (CaO)	4%
6	Ash	68-76%
7	Grade	F
8	Colour	Dark grey

Table.3.2 Properties of GGBS

SI.No.	Properties	Value
1	Colour	Off- white
2	Specific gravity	2.71
3	Fineness	>350m^2/kg
4	Bulk density	1200 kg/m^3
5	Calcium oxide	40%
6	Silica	35%
7	Alumina	13%
8	Magnesia	8%

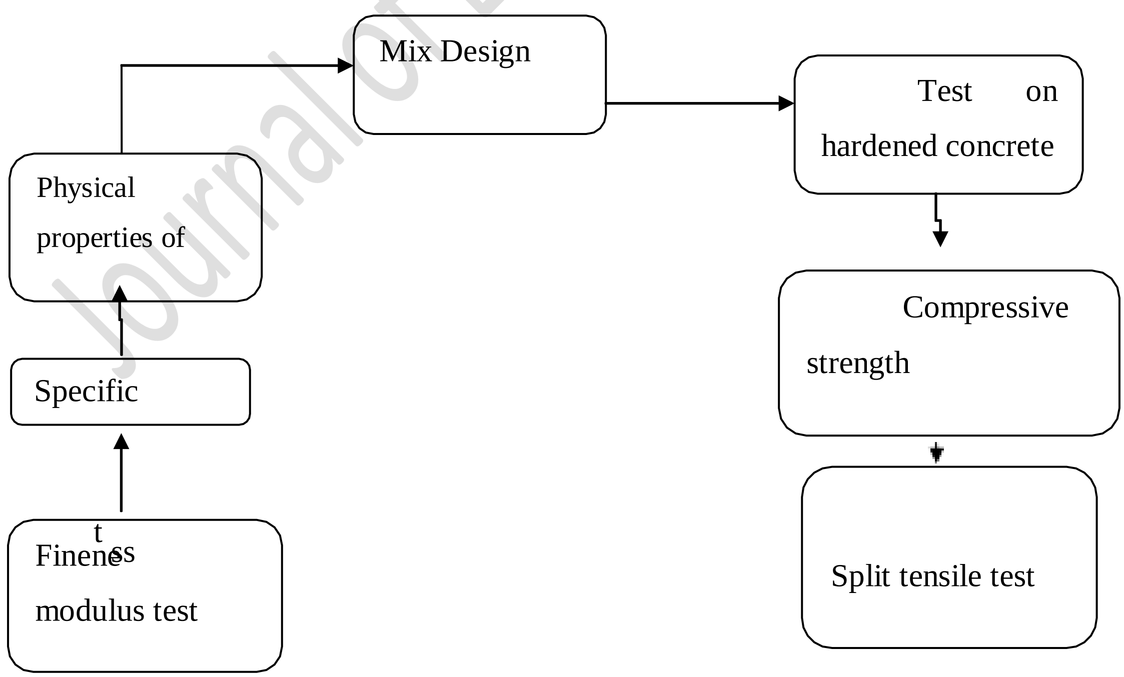
Table.3.3 Properties of sodium hydroxide (supplied by the manufacturer)

SI. No.	Properties	Value
1	Molecular formula	NaOH
2	Density	2.13 g/cm^3
3	Specific gravity	1.53
4	Sodium hydroxide	26.2%
5	Water	73.8%

Table.3.4 Properties of sodium silicate (supplied by the manufacturer)

SI. No.	Properties	Values
1	Molecular formula	Na_2O SiO_2
2	Molecular weight	184.04
3	Specific gravity	1.3-1.5
4	Na_2O	14.7%
5	SiO_2	29.4%
6	H_2O	55.9%

EXPERIMENTAL INVESTIGATIONS



Details of Mix proportion I (GGBS: Fly ash – 75: 25)

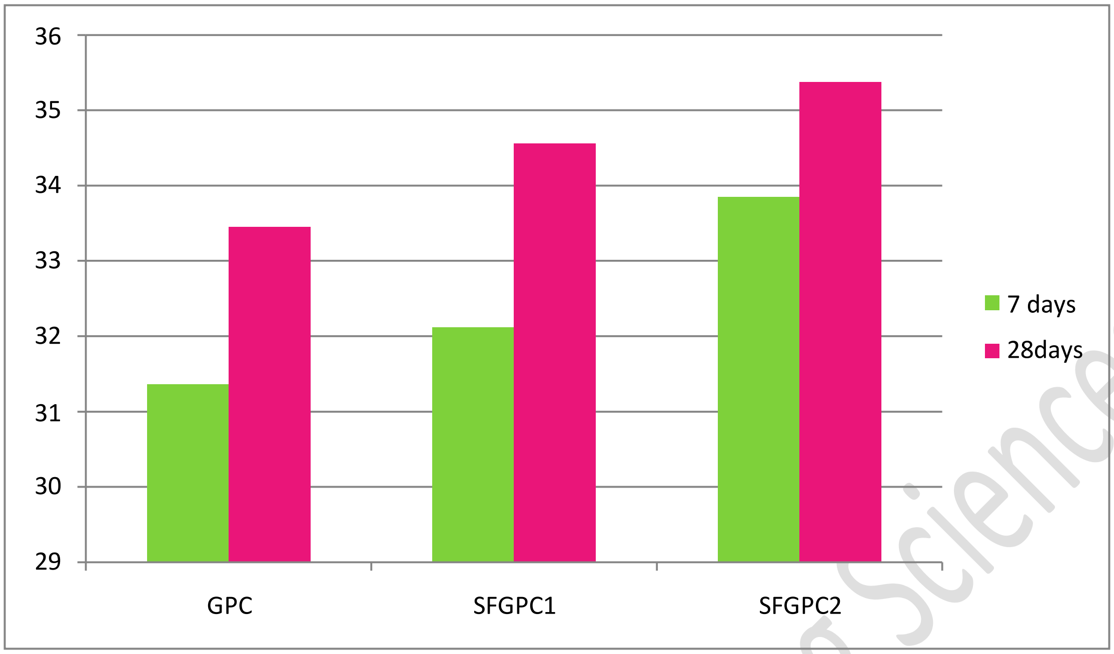
Materials	Mass (kg/m^3)
Coarse aggregate	1269
Fine aggregate	917
Fly ash	83
GGBS	246
Sodium hydroxide	53 (10 molar)
Sodium silicate	133
Super plasticizer	0.7
Water	51

MANUFACTURE OF GEOPOLYMER CONCRETE

Geoplymer concrete can be manufactured by adopting the conventional technique used in the manufacture of portland cement concrete. In the laboratory, the fly ash, GGBS, aggregates and required hybrid fibre (for required specimen) can be first mixed together dry in 60-litter capacity mixer for about three minutes. The aggregates have to be prepared in saturated-surface dry condition. The alkaline liquid has to be mixed with the super plasticizer and the extra water, if any. The liquid component of the mixture is added to the dry materials and the mixing continued usually for another four minutes. The fresh concrete could be handled up to 120 minutes without any degradation in the compressive strength.

Table: 5.1 Compressive strength valves (GGBS: Fly ash -75:25)

Designation (10)	GGBS(%)	Flyash(%)	Steel fibres	compressive strength in MPa(10M)	
				7 days	28days
S1	75	25	0	31.36	33.45
S2	75	25	0.1	32.12	34.56
S3	75	25	0.25	33.85	35.47

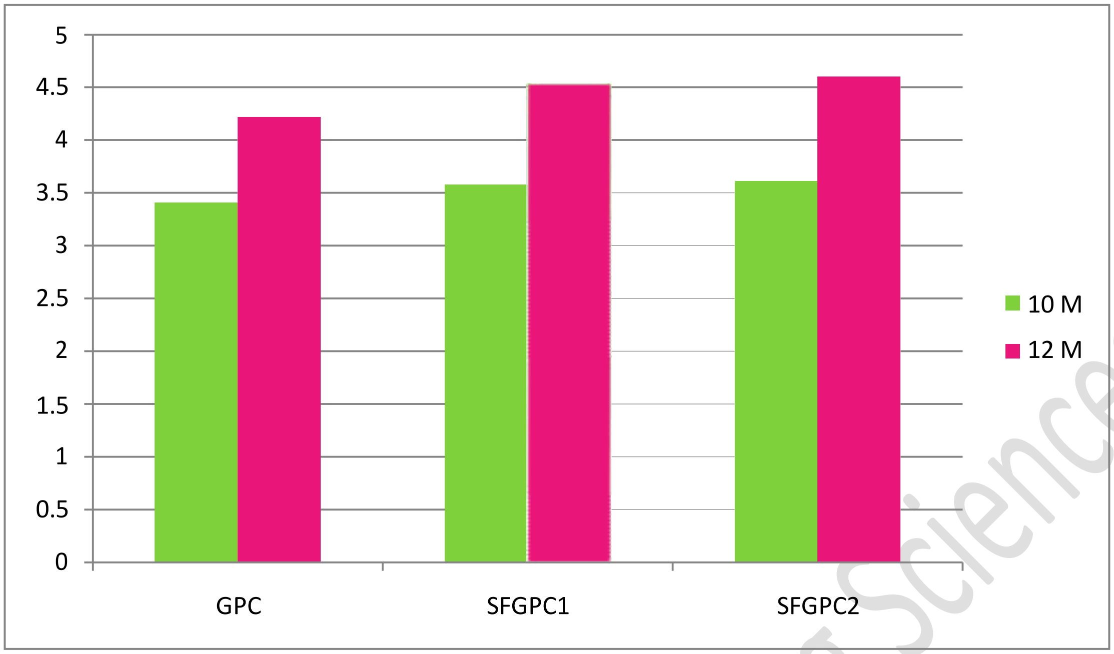


Fig; Graphical representation of compressive strength

From the above compressive strength results, it is observed ggbs and fly ash based concretes have achieved an increase in strength for 75%of GGBS and 25% of fly ash replacement of cement for 7 and 28 days days when compared to conventional concrete

Table: 5.3 Spilt tensile strength values (ggbs : fly ash 75:25)

Mix	GGBS	FLY ASH	STEEL FIBRES	SPILTTENSILE STRENGTH(Mpa) 7 Days	
				10M	12M
S1	75	25	0	3.41	4.22
S2	75	25	0.1	3.58	4.53
S3	75	25	0.25	3.61	4.60



Fig; Graphical representation of split tensile strength

From the above split tensile strength results, it is observed that ggbs and fly ash based concretes have achieved an increase in strength for 75%of GGBS and 25% of fly ash replacement of cement for 7 and 28 days when compared to conventional concrete

CONCLUSIONS AND FUTURE SCOPE

This chapter presents a summary of the present study, the major conclusions of the investigations done and scope for future research.

6.1 CONCLUSIONS

- The research reported herein comparised experinemtal study on the shear behaviour and strength of hybrid fibre reinforced fly ash and GGBS- based geopolymer concrete beams.
- Low calcium (ASTM Class F) dry fly ash obtained from the RMC plant was used as the source material to make geopolymer concrete. 30% of the Fly Ash by mass is replaced by the GGBS (ground granulated blast slagfernce).
- Addition of GGBS increases the strength of the geopolymer concrete. Hybrid fibre (combination of Steel fibre and basalt fibres) are used in this study.
- Sodium silicate solution and sodium hyroxide solution were mixed to form alkaline solution. This alkaline

solution have to be prepared one day before mixing with dry materials.

- The silicon and aluminium in fly ash reacted with alkaline solution to the form geopolymer paste that bound the loose aggregate and un-reacted materials to produce the geopolymer concrete.
- The aggregate consisted of coarse aggregate of maximum size 20 mm and fine aggregate confirming to zone II. The mix proportion and manifacturing process used to make the geopolymer concrete were based on the earlier studies available on geopolymer concrete.
- Total 36 geopolymer concrete cubes were made and tested. In this 36 cubes are made with Fly ash and GGBS-based hybrid fibre geopolymer concrete and 30 more cubes are made with fly ash-based geopolymer concrete .

- While the addition of fibres improved the first crack load significantly, the impronent was marginal for ulttimate load. The first crack load was found to have increased by about 75% at Steel 1% and Basalt 0.3% of fibre volume,
- These cubes tested for compression and tension behavior of geopolymer concrete.

The major conclusion drawn from this research are presented below:

- Geopolymer concrete in structural applications has led to the total elimination of cement from concrete, which ultimately becomes "Green Concrete"
- The fly ash, once considered as waste material, has found usefulness through Geopolymer concrete in construction industries and become a valuable material
- The crack partten observed for hybrid fibre reinforced geopolymer concrete beams were similar to those reported in the literature for steel fibre reinforced portland concrete. All beams failed in ductile manner accompained by crushing of the concrete in the compression zone.

  when campared to the specimens without fibres. However the increase in ultimate load was found to be only 44%.
- Energy absorbtion capacity increases for the beams with fibres compared to beams without fibres

1.2 FUTURE SCOPE

- Investigations on the effect of varying percentage of reinforcement on shear capacity of reinforced Geopolymer concrete beams.
- Study on the addition of various fibres in Geopolymer concrete and their effect on enhancement of strengths.
- Achieving ultra-high strength Geopolymer concrete by the addition of silica fume, quartz sand and quartz powder
- Attempts can be made to study shear behaviour of F&GHGPC beams for various shear span to depth ratio.
- This work can also be extended by applying cyclic and reverse cyclic loading.

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