Mechanical, Durability and Embodied Energy Analysis of Geopolymer Concrete with Fly Ash, GGBFS and Glass Fiber

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Abstract. Concrete is the second most widely used material next to the basic human needs. As the demand for concrete as a structural material grows, so does the demand for ordinary Portland cement (OPC).Global warming, on the other hand, has emerged as a major concern. Greenhouse gases, such as carbon dioxide emissions caused by human activity, are responsible for global warming. The cement industry is a major contributor to carbon dioxide emissions because it produces the same amount of carbon dioxide as their product. A sustainable alternative material that completely eliminates cement is Geopolymer concrete. This study presents results of an experimental program to determine mechanical, durability and embodied energy of Glass fibre reinforced Geopolymer Concrete contains fly ash and Ground Granulated Blast Furnace Slag (GGBFS) as binder materials in a constant proportion (50%×50%) each. Alkaline liquids to binder ratio by mass as 0.35 with proportion of sodium silicate (Na2SiO3) solution-to-sodium hydroxide (NaOH) 10 Morality solution by mass as 2.5. Coarse and fine aggregates are used in the proportion of 60:40, and Glass fibres are varied by percentages of 0(control mix), 1, 1.5 and 2 by volume of binder material. In the geopolymer concrete composite for the addition of 1% glass fiber compressive strength 21.95%, split tensile strength 52.5% and flexural strength 76.47% were found to be increased when compared with control mix. And results for 1% glass fiber found to be 52.82 MPa, 6.1 MPa and 15 MPa respectively, were as control mix found to be 43.3 MPa, 4 MPa and 8.5 MPa respectively. Highest residual compressive strength was attained for mix with 1% Glass fibres with 52.8MPa before and 48.9MPa after acid exposure. It is observed that least percentage of water absorption was attained for mix with 1% Glass fibres.

Keywords: *Fly ash, GGBS, Glass fiber, Alkaline liquids and Geopolymer concrete.*

1 Introduction

Geopolymer concrete has gained popularity recently due to its remarkable ability to replace cement concrete in the majority of its surroundings. It is an eco-friendly

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construction material and an alternative to Portland cement concrete, which is responsible for high CO_2 emission. Daidovits coined the term "geopolymer" in 1978 to describe materials with networks or chains of inorganic molecules. Utilizing waste products like fly ash and ground-granulated blast furnace slag (GGBS) allows for the creation of geopolymer cement concrete. Thermal power plants produce fly ash as a waste product, and steel plants produce ground-granule blast furnace slag as a waste product. Fibers are added to create fibre reinforced geopolymer concrete that can span cracks and provide some post cracking ductility. The fibers contribution is to make the concrete more resilient to loads of any kind. In other words, the fibers have a tendency to increase strain at maximum load while providing significant energy absorption in the load versus deflection curve's post peak region. It is reasonable to anticipate that the inclusion of fibers in the concrete body will increase the resistance of reinforced structural members to cracking, deflection, and other serviceability conditions. The energy present in building materials serves as an indicator or predictor of the energy that will be used during the building's lifecycle. Materials differ in the amount of energy needed to produce them. Thus, choosing materials with low environmental impact potential lessens the effect of buildings. Utilizing locally produced or recycled materials rather than imported ones reduces the need for transportation. The energy used in the production of building materials was determined based on the overall energy needed by the production unit weight of the material.

Studies on Strength properties of fly ash and GGBS based geopolymer concrete. (J. Guru Jawahar 2015) The goal of this research was to examine the effects of class F fly ash (FA) and ground granulated blast furnace slag (GGBS) on the mechanical properties of geopolymer concrete (GPC). (G. Jayarajan 2021) in this, M40 and M60 were the ratios used in this project work. In comparison to grade control concrete M40, Flyash and GGBS show better results in cement replacement by weight when it comes to hardened concrete properties like compressive resistance and tensile strength. (Ganesh 2019) this research work investigates Fly ash of the GGBS blend type, cured in a hot environment, with the ideal molarity. Using a compaction factor test, the fibre reinforced geopolymer concrete's new properties were determined.

(J D Chaitanya kumar 2016) to research how glass fibre behaves in concrete. To meet the demands of modern construction, the current trend in concrete technology is to make concrete stronger and more durable. (L Krishnan 2014) this study shows Ground Granulated Blast Furnace Slag (GGBS) powder is added to fly ash-based geopolymer concrete to overcome its main drawbacks, which include slow concrete setting at room temperature and the requirement for heat curing.

2. Materials and Methodology

2.1 Materials

In the present experimental work, studies on mechanical and durability properties of Glass fiber reinforced geopolymer concrete with varying percentage of glass fiber were carried out. For this experimental study, the ingredients used are cementious binders such as Class-F Flyash & GGBS, Alkaline liquids, Glass fiber, M-sand as fine aggregates, Coarse aggregates 16mm down and Super plasticizer Master Glenium SKY 8233 was used. In addition, Glass fibers are added in varying proportions (0%, 1%, 1.5%, 2%) to examine the consequence it would have on the mechanical as well as durability characteristics of the geopolymer concrete. Physical properties like specific gravity and fineness modulus of materials are shown in Table 1 and Table 3. Chemical properties flyash and GGBS are shown in Table 2. GFRC is a strong, lightweight material that can be cast into any shape, texture, or colour that is desired. The strength that is brought to the table is one of the key

attributes. The high concentration of glass fibres gives it tensile strength. It offers higher flexural strength and is far superior to ordinary concrete.

Table 1. Physical Properties of Materials.

Materials	Specific Gravity	Fineness Modulus	Code
Fly Ash	2.23	370	IS 3812:2013 Part1
GGBFS	2.91	379	IS 3812:2013 Part1
M-Sand	2.48	2.96	IS 383:2016
Coarse Aggregate	2.74	3.28	IS 383:2016

Table 2. Chemical properties of materials

Material	Fly Ash	GGBFS
MgO%	1.81	7.83
MnO%	--	0.12
SO_3%	0.16	0.24
Cl%	0.004	0.009
Sulphur%	--	0.51
Glass Content	--	92
$SiO_2.Al_2O_3$%	86.56	--

Table 3. Properties of Glass Fiber

Specifications	Results
Number of Fibers	>200 million/kg
Aspect Ratio	12:3
Specific Surface Area	105 m^3/kg
Specific Gravity	2.68
Elastic Modulus	72 GPa

2.2 Methodology

This study aims at investigating the effectiveness of varying percentages of glass fiber in order to enhance the mechanical and durability characteristics of glass fiber reinforced geopolymer concrete and to establish an embodied energy comparison between conventional concrete and GFRGC.

1. To examine basic tests of binders, fine aggregates and coarse aggregates.
2. To determine the amount of materials needed to prepare GFRGC.
3. To prepare samples of mix 4 with varying glass fibre percentages (0%, 1%, 1.5%, & 2%).
4. To evaluate fresh properties of GFRGC by conducting Slump test and hardened properties of GFRGC by conducting Compressive strength, Split tensile test and Flexural strength test on Cubes, cylinder and Beams respectively casted in laboratory.
5. To evaluate the durability properties of GFRGC by conducting acid attack test and water absorption test.
6. To compare embodied energy between Normal concrete (NC) and GFRGC per unit meter.

2.3 Mix Proportion

Geopolymer concrete does not have a standardized method of mix design like ordinary cement concrete does. Therefore, based on the trail mixes and by referring to literature available (J. Guru Jawahar 2017) the mix design adopted in this study is asper Table 4.

Table 4: Mix Design Details

Ingredients	Quantity (kg/m^3)
Fly Ash	204.5
GGBFS	204.5
M-Sand	739.2
Coarse Aggregate	1108.8
Sodium Hydroxide Solution (10M)	41
Sodium Silicate Solution	102
Superplasticizer	12.3
Water	81.8

3 Results and Discussion

The strength of glass fiber reinforced geopolymer concrete using fly ash and GGBS is studied, and the effect of varying percentages of glass fiber on geopolymer concrete is discussed along with durability and energy analysis.

3.1 Fresh Concrete Properties

A slump test is an in-situ or laboratory test conducted to measure the consistency of concrete. It aids in identifying concrete mix uniformity and workability characteristics. It was carried out in accordance with IS 1199-1959 and a slump cone with a height of 30 cm, a top opening of 10 cm, and a bottom opening of 20 cm was used.

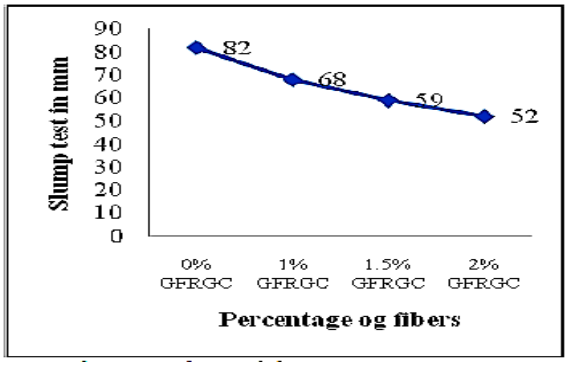

Fig. 1. Slump value with respect to percentage of Glass fibers

3.2 Hardened Concrete Properties

In simple language, the strength of concrete means the maximum amount of load that it can handle. In common practice, it is the strength of the concrete which is considered its most valuable property. In fact, high-strength concrete is synonymous with good-quality concrete. The strength of concrete can be determined by its compressive strength, split-tensile strength and flexural strength.

3.2.1 Compressive strength

The compressive strengths of GFRGC with varying glass fiber content percent of 0 %, 1 %, 1.5 % and 2% consisting were tested for 7days, 14days and 28days respectively are shown in Figure 2. There was considerable increment in the compressive strength due to addition of 1%, 1.5% and 2% of glass fiber was found to increase by 21.95%, 12.9% and 1.84% for respectively compared to GC without fibres.

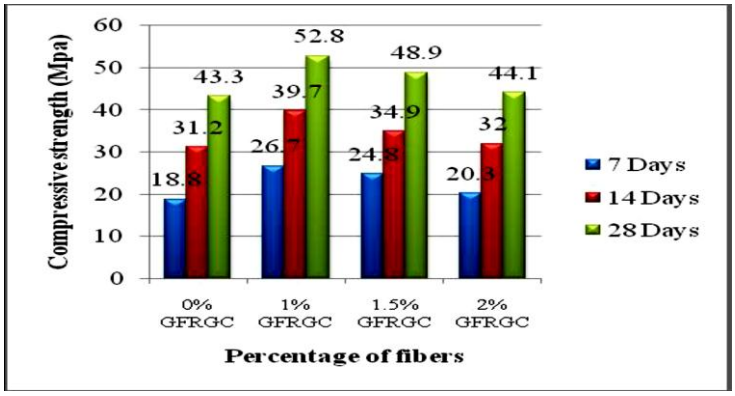

Fig. 2. Compressive strengths of various specimens for 7, 14 & 28days

3.2.2 Split tensile strength

The split tensile strengths of GFRGC with varying glass fiber content percent of 0 %, 1 %, 1.5 % and 2% consisting of Flyash, GGBS and alkaline solution were tested for 7days and 28days respectively are shown in Figure 3. There was considerable increment in the split-tensile strength due to addition of 1%, 1.5% and 2% of glass fiber was found to increase by 52.5%, 32.5% and 12.5% for respectively compared to GC without fibres.

3.2.3 Flexural strength

The flexural strengths of GFRGC with varying glass fiber content percent of 0 %, 1 %, 1.5 % and 2% consisting of Flyash, GGBS and alkaline solution were tested for 7days and 28days respectively are shown in Figure 4. There was considerable increment in the flexural strength due to addition of 1%, 1.5% and 2% of glass fiber was found to increase by 52.5%, 32.5% and 12.5% for respectively compared to GC without fibres.

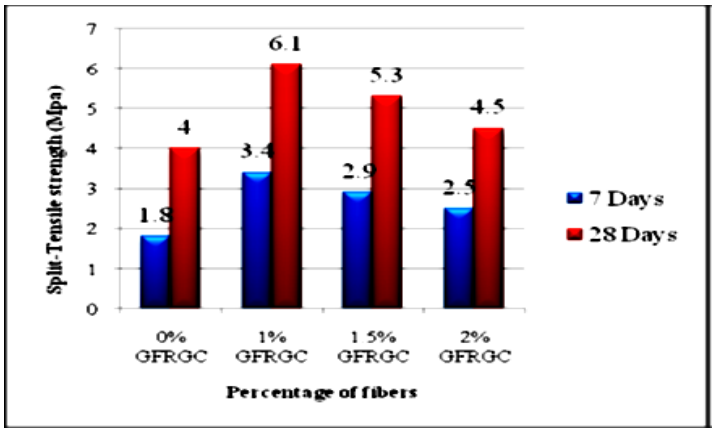

Fig.3. Split-tensile Strength Test Results

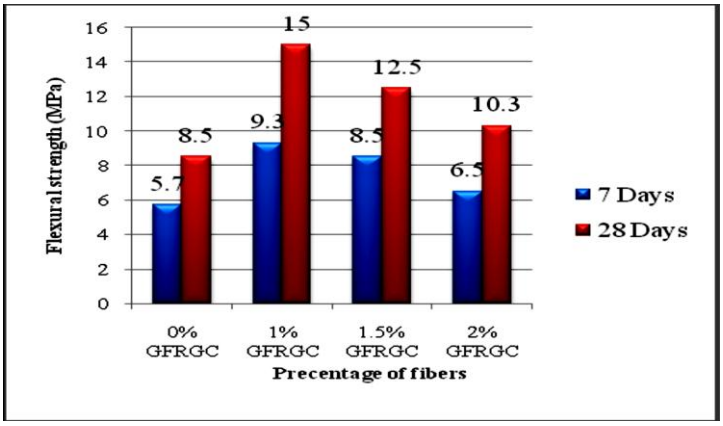

Fig. 4. Flexural Strength Test Results

3.3 Durability Characteristics

Durability is key to having a sustainable concrete structure. Concrete structures frequently show severe premature deterioration due to the use of inappropriate materials, poor construction practices, curing and mix designs. This is a global problem that annually costs the public and private sectors worldwide billions of rupees.

It is difficult to evaluate concrete's durability in order to determine how long it will continue to operate being. used. However, it's important to recognize how ultimately sustainable structures will be.

3.3.1 Acid immersion test

To determine durability of specimens, acid attack test was carried out as per Verapathran & Murthi, 2018. Specimens immersed in 5% concentrated Sulphuric acid solution for 30days. From Figure 5, it was observed loss in weight after 30 days acid exposure are 3.2 kg, 1.9 kg, 2.3 kg and 2.5 kg with respect to 0%, 1%, 1.5% and 2% GFRGC. From Figure 6, it was observed that percentage weight loss of compressive strength of specimens after acid exposure for Mix-1, Mix-2, Mix-3 and Mix-4 were 25.3%, 7.9%, 5.8% & 5.3% respectively.

3.3.2 Water Absorption Test

The cube specimens of all three mixes were immersed in water for not less than 48hours after 28days ambient curing followed by 24hours of oven curing to dry the specimen completely. From Figure 7, it is observed that percentage water absorption of GFRGC with varying Glass fibre content 0%, 1%, 1.5% & 2% was 4.9%, 3.2%, 3.3% & 3.4% respectively.

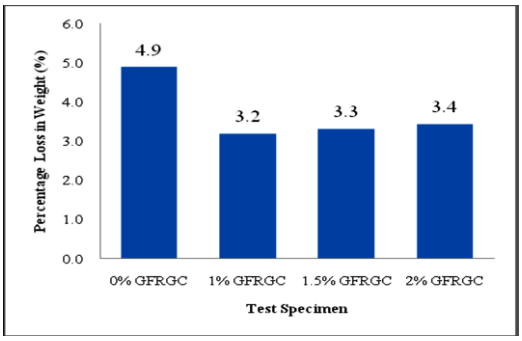

Fig. 5. %Loss of Weight After Acid Exposure

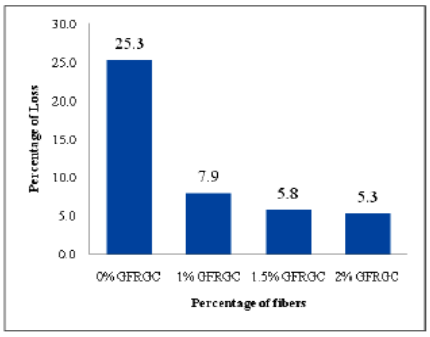

Fig. 6. Residual Compressive Strength

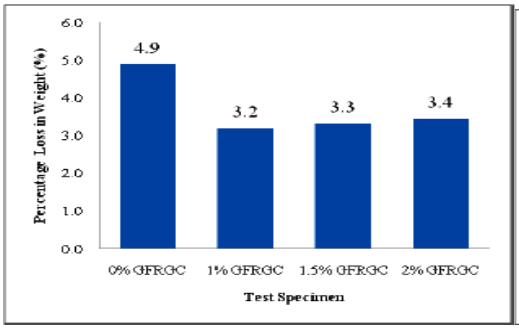

Fig. 7. % Water Absorption

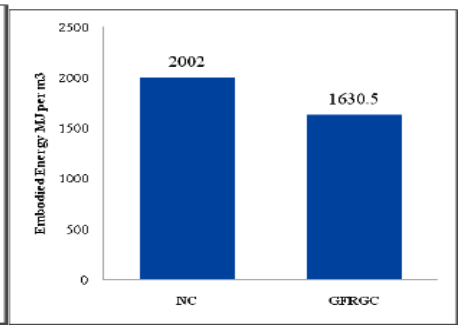

Fig. 8. Comparison of Embodied Energy with NC and GFRGC

3.4 Embodied Energy Analyses

Embodied energy is the total amount of energy used throughout the entire building-production process, from the extraction and processing of raw materials to manufacturing, transportation, and at last delivery of products. An energy analysis was carried out to compare the embodied energy and carbon emissions for normal concrete and GFRGC per unit meter. Here, M40 grade is considered for NC with consideration to IS 10262:2019. Similarly, the embodied energy and carbon emissions were also calculated by referring to B J Mathew 2013 and L K Turner 2013 respectively as shown in Table 5, 6 & 7. From Figure 8, it was observed that the embodied energy consumed by GFRGC is 1630.5 MJ and normal concrete is 2002 MJ. GFRGC consumed less when compared to normal concrete. From Figure 9, it was observed that the embodied carbon consumed by GFRGC is 310.3 kgCO2 and normal concrete is 396.9 kgCO2. GFRGC consumed less when compared to normal concrete.

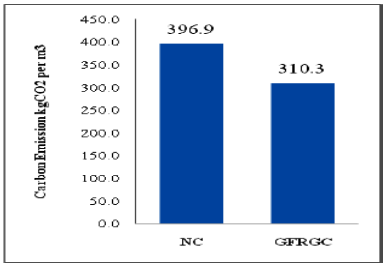

Fig. 9. Comparison of Carbon Emission with NC and GFRGC

Table 5. Embodied Energy and Carbon Emission for 1 m3 of NC

Material Description	Quantity Of Materials (Kg)	Energy (MJ/kg)	Carbon Footprint ($kgCo_2/kg$)	Total Amount Of Embodied MJ per m3	Total Amount Of $kgCO_2$ per m3
Cement	412	4.53	0.82	1866.36	337.84
Fine Aggregate	642	0.02	0.0139	12.84	8.9
Coarse Aggregate	1228	0.1	0.0408	122.8	50.1024
			Total	2002 MJ	396.9 $kgCO_2$

Table 6. Embodied Energy for 1 m3 of GFRGC

Material	Energy (MJ/kg)	Quantity per m^3(kg)	Energy per m^3(MJ)
GGBS	0.31	204.5	63.4
Fly Ash	0	204.5	0.0
Coarse Aggregate	0.1	1108.8	110.9
Fine Aggregate	0.02	739.2	14.8
NaOH	20.5	41	840.5
Sodium Silicate	5.37	102	547.7
Glass fibers (1%)	13	4.09	53.2
Total Energy of GFRGC per m^3 MJ			1630.5

Table 7. Carbon emission of GFRGC for 1 m3

Material	Carbon emission (kgCO2/kg)	Quantity per m3 (kg)	Carbon emission per m3 (kgCO2)
GGBS	0.0796	204.5	16.3
Fly Ash	0.027	204.5	5.5
Coarse Aggregate	0.0408	1108.8	45.2
Fine Aggregate	0.0139	739.2	10.3
NaOH	1.915	41	78.5
Sodium Silicate	1.514	102	154.4
Glass fibers (1%)	0.0021	4.09	0.01
Total Emission of GFRC per m3 kgCO2			310.3

4 Conclusion

The findings of this study demonstrate that the inclusion of glass fibres in the geopolymer concrete matrix significantly affects the specimen's mode of failure. The fibres significantly affect the durability and brittleness of concrete under compression and tension in additionto increasing the specimen's overall strength.

1. The compressive strength was found to increase by 21.95%, 12.9% and 1.84% for incorporation of 1%, 1.5% and 2% Glass fibres respectively compared to GC without fibres.
2. The results showed that the split tensile strength was found to increase by 52.5%, 32.5% and 12.5% for incorporation of 1%, 1.5% and 2% Glass fibres respectively compared to GC without fibres.

3. The results showed that the flexural strength was found to increase 76.47%, 47.05% and 21.17% for incorporation of 1%, 1.5% and 2% Glass fibres respectively compared to GC without fibres.
4. Geopolymer concrete without fibre reinforcement had the highest loss in weight due to acid exposure, and the loss in compressive strength decreased with an increase in fibre content. GC without fiber had a loss of 3.2%, and fibre reinforced GC had an average loss in weight of 2.23%.
5. It is observed that least percentage of water absorption was attained for mix with 1% Glass fibres.
6. GFRG concrete shows significantly less embodied energy and carbon emission compared to normal concrete. There was a reduction of 22.78% in embodied energy and 27.91% in carbon emission when compare to normal concrete per unit meter.

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