

Research

An investigation on workability and strength on compression of GPC with addition of different aspect ratio glass fibers

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Abstract

The heating of limestone and other materials to high temperatures to produce Ordinary Portland cement (OPC), a key component in concrete releases of carbon dioxide CO₂ which makes the construction industry a notable contributor to greenhouse gas emissions. The search for more sustainable alternatives has led to the exploration of alkali-activated materials as a replacement for OPC. Alkali-activated materials are a class of binders that can be used in concrete production without the need for traditional cement. These materials often include industrial by-products such as fly ash, GGBFS (sometimes also called GGBS) (Ground Granulated Blast Furnace Slag), and other waste materials. The development and adoption of alkali-activated materials represent a promising avenue for reducing the environmental impact of the construction industry. On-going research and collaboration are crucial to addressing technical challenges and promoting the widespread use of these alternative binders. The exploration and utilization of alternative materials such as GGBFS, fly ash, and geopolymer concrete play a crucial role in mitigating the environmental impact of the construction industry, particularly in terms of reducing CO₂ emissions and utilizing industrial by-products effectively. A good concrete mix is obtained from combination of different size of aggregates. Addition of fibers plays a crucial role in enhancing the tensile strength of concrete. Similar synergy of addition of different aspect ratio of optimum dosages fibers as of different size of aggregates may improve strength and ductility of concrete. Short fibres can stop the propagation of micro-cracks with enhancement of toughness, and long fibres can stop the propagation of macro-cracks. From the aforementioned perspective, it is preferable to add the same volume of fibre with a different aspect ratio to improve the pre- and post-cracking performance of concrete. It also aids in boosting maximal strength. This study aims in preparing geopolymer concrete with graded glass fibres in order to investigate improvement the strength in compression and workability.

Keywords Geopolymer concrete · Graded fiber · Alkaline solution · Slump value · Compressive strength

1 Introduction

The environmental concerns associated with release of carbon dioxide (CO₂) on production of ordinary Portland cement (OPC). It highlights the release CO₂ during the burning of fossil fuels and the production process of OPC, which contributes to greenhouse gas emissions. The energy-intensive nature of OPC production is underscored by the comparison with steel and aluminium production. Brough [1], noted that every tonne of cement production

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results in approximately one tonne of CO₂ emissions. To address these environmental issues, Muthusamy et al. [2] suggest the use of alternative cementitious materials such as fly ash, blast furnace slag, and silica fume in concrete production. These materials, often considered waste, are abundant and can potentially reduce greenhouse gas emissions associated with concrete production while also addressing the challenge of waste disposal. Davidovits [3], explored the use of fly ash, blast furnace slag, and silica fume to create geopolymers. According to Davidovits [4–6], the polymeric reaction of cementitious materials with alkaline liquids can lead to the formation of binders. This class of solid materials is produced through the reaction of alumina silicate powder with alkaline liquids, offering an alternative to traditional OPC-based binders. To avoid environmental impact of OPC production, utilization of waste materials, such as fly ash, blast furnace slag, and silica fume, for the production of alternative cementitious materials like geopolymer may be explored. This approach targets to reduce greenhouse gas emissions and addresses the issue of waste disposal associated with these materials.

The historical context of the need for fire-resistant structures aftermath of world war in Europe was sensed and was reflected in the works of Davidovits [4–6]. This observation highlights the potential of geopolymers in addressing specific requirements, such as fire resistance, in construction. To eliminate the use of OPC entirely in concrete production, Davidovits et al. [7] suggested the use of pozzolanic materials like ground granulated blast furnace slag (GGBS), mixed with alkaline liquids to produce a paste. The reaction between the silicon and calcium in GGBS with sodium hydroxide (NaOH) leads to the formation of geopolymer concrete, offering an OPC-free alternative. Studies by Ankur et al. [8] and Amer [9] suggest that up to 60% of OPC by mass can be replaced by fly ash. Geopolymer concrete is referred to by various names, including alkali-activated concrete and organic polymer concrete. A noteworthy point is the claim that geopolymer concrete can reduce greenhouse gas emissions from the concrete industry by 80%, as identified by Davidovits et al. [7]. This assertion underscores the potential environmental benefits of utilizing geopolymers as an alternative to OPC in concrete production.

Various alkali compounds, including mild acid non-silicic compounds, alkali hydroxide, and activators like NaOH, Na₂SO₄, Na₂CO₃, and Na₂SiO₃, are used in the production of geopolymer concrete. According to Davidovits [5, 6], researchers often consider liquid sodium silicate, also known as water glass, as the most effective activator. The composition of the alkali silicate solution is described in terms of the SiO₂:Na₂O ratio or mica modulus (Ms) of the water glass activator. The impact of alkaline activation increases with higher Na₂O concentration but decreases as the silica gel content decreases. This observation holds true even with a stable solid sodium silicate concentration. Geopolymer concrete is highlighted as having superior durability properties compared to OPC concrete, particularly against chemical attacks. It is less permeable, possesses higher compressive strength, and offers early strength and better durability. studies conducted by Das et al. [10], Prakash et al. [11], and Jaf et al. [12] that explore the effects of additives on geopolymer concrete. Jaf et al. [12] employed machine learning techniques and multi-scale models to evaluate compressive strength of GPC. Addition of fibers of different aspect ratio with 1% copper fiber by volume of concrete increases compressive strength of high strength concrete [13]. Impact of addition of natural fiber on long term behaviour of GPC was well documented by [14]. While copper fiber increases strength, substitution of copper slag with OPC decreases compressive strength and increases workability [15].

These studies suggest that the addition of calcined clay, shorter fibers, and certain types of fibers can enhance compressive strength. Factors such as the molarity of NaOH solution, curing temperature, and the addition of nano silica are discussed as influencing the compressive strength of geopolymer concrete. According to Verma et al. [16], higher molarity of sodium hydroxide concentration and increased curing temperature contribute to increased strength.

In the preparation of concrete, the use of uniform graded aggregates is emphasized, indicating that the uniformity in aggregate size plays a crucial role in the performance of the concrete. The addition of fibers at optimum dosages, with specific diameters and different aspect ratios, is noted as a factor that enhances concrete strength. Aspect ratio refers to the ratio of the length of the fiber to its diameter. The term “graded fiber geopolymer concrete” is introduced to describe the practice of adding fibers of different lengths to geopolymer concrete. This approach involves combining short-length fibers to impede the propagation of micro-cracks and long fibers to arrest macro cracks. The ultimate strength of concrete depends on the addition of short-length fibers, emphasizing their role in achieving high-strength characteristics. Instead of adding fibers with the same aspect ratio, the above discussion suggests that it is better to add the same volume of fiber with different aspect ratios. The combination of fibers with different aspect ratios is said to improve performance both in the pre-cracking and post-cracking stages as suggested by Lawler et al. [17], Kasagani and Rao [18–20].

Graded fiber refers to the use of fibers with different aspect ratios, either mono fibers with varying ratios or a mix of different fibers with dissimilar aspect ratios. The passage emphasizes that when this approach is applied to concrete

with glass fibers, it is termed as graded glass fiber reinforced concrete (GGFRC). The addition of glass fibers with different aspect ratios to geopolymer concrete leads to the designation of graded glass fiber reinforced geopolymer concrete (GGFRGPC). This implies that the use of various lengths and aspect ratios of glass fibers is intentional in the design of the concrete mixture. GGFRGPC is noted for enhancing the ductility of joints in the concrete. The increased ductility is beneficial in reducing the reliance on transverse reinforcement in the joints. As a result, the requirement for transverse reinforcement is reduced in GGFRC compared to other types of reinforced concrete. The concept of graded fiber specifically in the context of geopolymer concrete, highlighting addition of glass fibers with different aspect ratios are intentionally mixed in GPC. The advantages of GGFRC include increased ductility, reduced reliance on transverse reinforcement, and prevention of reinforcement jamming at joints, as supported by the study conducted by Kasagani et al. [21].

Despite the availability of a good number of references in the field of GPC with fiber, it is noteworthy to mention that none of the existing research works have recommended the use of graded fiber in the preparation of geopolymer concrete to increase its strength. The concrete strength in compression is an important parameter. This parameter is vital in determining the overall performance and structural integrity of the concrete.

2 Research significance

The conclusion drawn from the previous recommendations is that there is a need for a comprehensive and systematic experimental study to explore the strength properties of geopolymer concrete, particularly with the addition of graded fiber. The main objective of the research work is to enhance the strength of geopolymer concrete by incorporating fibers with different aspect ratios. The specific focus of the research is on evaluating the effects of graded fiber on both the workability and compression strength of geopolymer concrete. Workability is an essential property that influences the ease of handling and placing the concrete during construction. Reduction of carbon footprint, preparing a new concrete with enhanced properties in pre and post cracking stage with provision for ease handling and placing of concrete is the motto of this research work. There is a need for research in the area of geopolymer concrete with graded fiber, outlining the objectives to enhance concrete strength and to evaluate its impact on workability. The intention is to fill the existing gap in knowledge and provide valuable insights for the improvement of geopolymer concrete physical properties and workability.

3 Experimental investigation

The experimental study is focusing on fundamental characteristics related to the strength and workability of geopolymer concrete. Geopolymer concrete is an innovative alternative to traditional Portland cement concrete, utilizing industrial by-products like fly ash or ground GGBFS along with alkali-activated solutions. As there is no specific mix design is available for GPC, the conventional established methods typically used for traditional concrete is taken to produce geopolymer concrete mixes. The variation is adopted in the dosage of the amount of volume fraction of graded fibre. The flow chart of the experimental program is presented in Fig. 1.

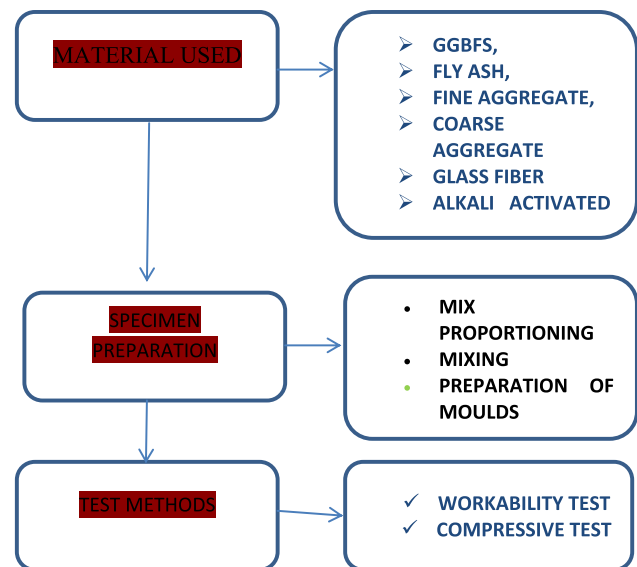
The ingredients used to form geopolymer concrete is as mentioned below.

- GGBFS (Ground Granulated Blast Furnace Slag)
- Fly ash
- Na_2SiO_3 solution (SS)–Sodium silicate solution
- NaOH solution (AAS)–Activated alkali solution
- Graded glass fiber
- Aggregates

Testing focus: Our study focuses on fundamental characteristics related to the strength and workability of geopolymer concrete. Two key tests mentioned are:

- a. Slump tests: These are conducted to measure the workability or flowability of fresh concrete. It gives an indication of how easy the concrete can be placed and compacted.

Fig. 1 Flow chart of experimental program



- b. Compressive tests: These evaluate the ability of the concrete to withstand axial loads or pressure. It's a crucial test for assessing the structural strength of the material.

The details of the test results, including the slump value, weight of concrete, and compression strength at 56 days, are likely provided in Table 3.

3.1 Materials and their properties

The qualities of the materials used to make the specimen are explained here. It was necessary to first gather supplies and equipment and verify their availability. Tests were done on concrete specimens that included varying percentages of glass fiber to see how graded glass fiber affected the specimens' workability and compression strength.

3.1.1 GGBFS

For preparation of GPC, GGBFS is used to which is a by-product of steel industry.

3.1.2 Fly ash

Fly ash is also a substitution of OPC. It is utilized in concrete as a mineral additive. It is of type C- class.

- Possess pozzolanic and cementitious characteristics.
- Low level of calcium

3.1.3 Fine aggregate

For fine aggregate, river sand that is easily found locally was used for this study. Sieving was done for conforming the zone and found as grading zone-III as per IS 383-1970 [22] and other fine aggregate properties and are confirmed as shown in Table 1.

3.1.4 Coarse aggregate

The material used in concrete is hard granite stone, with a maximum size of 20mm. It is prepared by cleaning and drying. Coarse aggregates are tested according to IS: 383-1970, including gradation, specific gravity, particle size distribution,

Table 1 Physical properties of materials

S.No.	Properties	GGBS	Fly ash	Fine aggregate	Coarse aggregate
1	Type			Uncrushed	Crushed
	Colour	Off-white			
2	Bulk density Kg/m ³	1000–1100 g/m ³ (loose) 1200–1300 kg/m ³ (vibrated)		1600	1460
3	Specific gravity	2.9	2..17	2.61	2.7
4	Specific surface area	> 450m ² /kg	380 m ² /kg		
5	Maximum nominal size, mm				20
6	Fineness modulus			2.7	6.8
7	Grading zone			III	
8	Impact value				6.83
9	Crushing value (%)				52.6
10	Water absorption (%)				0.52

impact value, abrasion value, and flakiness and elongation index. These tests ensure the quality and suitability of the aggregates for glass fiber-reinforced concrete.

3.1.4.1 Glass fiber Glass fiber is an inorganic non-metallic material with excellent performance. Its advantages are good insulation, strong heat resistance, good corrosion resistance, and high mechanical strength, but its disadvantages are brittleness and poor wear resistance. The glass fiber is mainly made of pyrophyllite, quartz sand, limestone, dolomite, boracite, and boehmite through high-temperature melting, wire drawing, winding, weaving, and other processes.

Glass fiber has a tensile strength of 1700 MPa, an elasticity modulus of 73 GPa, a specific gravity of 2.6, and a filament diameter of 14 μm as shown in Fig. 2.

As per Kasagani and Rao [19, 20], fiber of length more than 3 mm may be used as fibers of length less than 3 mm have lesser grip length to develop full strength. Fibers having lengths more than the length that is required for developing full strength fail by snapping. Micro fibers are capable of enhancing post peak toughness [23] and for higher volume fraction of fibers failure is due to fiber pull out where as for less volume fraction it is due to pull out mechanism. Different percentage of fiber used in this study are tabulated in Table 2.

3.1.5 X-ray fluorescent test

X-ray fluorescence (XRF) spectroscopy is a non-destructive analytical technique used to determine the elemental composition of a material. In our case, Ground Granulated Blast Furnace Slag (GGBS) and Ordinary Portland Cement (OPC) were subjected to XRF analysis to determine their compound compositions as shown in Fig. 3.

3.1.5.1 XRF spectrometer XRF spectrometer is an instrument used for X-ray fluorescence analysis. It measures the intensity of fluorescent X-rays emitted by a sample when it is irradiated with X-rays.

3.1.5.2 Sample preparation GGBS and fly ash samples were made by grinding the samples into a fine powder to ensure homogeneity and representativeness. A preliminary X-ray source was used to irradiate the samples and with emission X-rays, the inner-shell electrons of the atoms in the sample to become excited. The XRF analyzer detects and measures the energy and intensity of the fluorescent X-rays emitted by the sample, allowing the identification and quantification of elements in the sample. The XRF analysis provides information about the elemental composition of the GGBS and fly ash samples such as the concentrations of various oxides and compounds present in the samples as shown in Table 3. The results obtained from the XRF analysis are interpreted to understand the chemical composition of GGBS and fly ash. This information is valuable for quality control in the production of these materials and ensuring they meet the desired specifications for construction purposes.

Fig. 2 (a) Alkali resistant glass fiber of length 9 mm and 12 mm (b) Alkali resistant glass fiber of length 20 mm



Table 2 Percentage of glass fibre used in 4 batches of mixes

Mix designation	GF0	GF0.1	GF0.15	GF0.2	9 mm-40 %
Glass fibre (%)	0	0.1	0.15	0.2	12 mm- 30%
Glass fibre length (mm)	0	9,12, 20	9,12, 20	9,12, 20	20 mm- 30%

Fig. 3 The X- Ray fluorescent spectrometer to find constituents of fly ash and GGBS



Table 3 Composition of GGBFS and fly ash properties as per Xrf

Fly ash			Ground-granulatedBFS (GGBS)	
Constituent	Unit	Value	Unit	Values
Al ₂ O ₃	%	2.956	%	5.031
CaO	%	79.214	%	71.76
SiO ₂	%	10.502	%	16.84
Fe ₂ O ₃	%	3.972	%	3.28
SO ₃	%	1.48	%	1.56
K ₂ O	%	0.632	%	0.737
TiO ₂	%	0.800	%	0.547
MnO	%	0.176	Ppm	840.4
SrO	ppm	665.5	Ppm	368.8
ZrO ₂	ppm	409.4	Ppm	324.7
V ₂ O ₅	ppm	173.3	Ppm	126.9
BaO	ppm	420.2		

Other oxides like Cr₂O₃, NiO, ZnO, Rb₂O, ThO₂ etc are present in small amount less than 50-60ppm

3.1.6 Mix design

The concrete mix was prepared with the following ratio: binder: sand: hard granite stone: solution = 1: 1.53: 1.87: 0.6. Vikash and Rao [24] as shown in Table 4. Use of supplementary cementitious materials, GGBS (Ground Granulated Blast Furnace Slag) and Fly Ash in a 60:40 ratio were used in the concrete mix. Different percentages of glass fiber were added to the concrete as 0%, 0.1%, 0.15%, and 0.2% by volume. Three fiber lengths were used in each specimen: 9 mm, 12 mm, and 20 mm. The ratio of these fibers in each specimen was 40%, 30%, and 30%, respectively. Three fiber lengths were used in each specimen: 9 mm, 12 mm, and 20 mm. The ratio of these fibers in each specimen was 40%, 30%, and 30%, respectively. A slump test was conducted on the fresh concrete to assess workability.

All the materials were weighed and prepared according to the mix design proportion. To obtain a uniform mix, fine aggregates, GGBFS and fly ash were poured in mixture machine and then mixed by rotating the drum without the alkaline solution. After that activator alkaline solutions were added and mixed again until a uniform-colored mix was obtained. After completing this process, concrete was dropped on a flat and clean plate and glass fibers were added as per the calculated quantity and then the materials were mixed thoroughly manually. Fresh properties of concrete were determined and moulds were filled and compacted.

Testing and results: Various parameters such as slump value of fresh concrete, weight of concrete at different stages, compressive strength at 56 days were tabulated in Table 5. This study aims to understand the impact of different glass fiber percentages and lengths as tabulated in Table 2 on the fresh and hardened properties of concrete. The tabulated results in Table 5 would provide a comprehensive view of how these variations influence aspects like workability and strength over time.

Table 4 Mix proportioning ratio of plain concrete and GPC with respect to 1 kg binder

Mix designation	Binder (Fly ash: GGBFS) 40:60)		Coarse Aggregate (kg)	Fine Aggregate (kg)	Solution (NaOH+ Na ₂ SO ₃ =0.6 kg In the ratio of 1:2.5		Glass fiber		
	Fly Ash(kg)	GGBFS(kg)			NaOH (kg)	Na ₂ SO ₃ (kg)	9 mm (gram)	12 mm (gram)	20 mm (gram)
GF0	0.4	0.6	1.53	1.87	0.172	0.428	0	0	0
GP0.1	0.4	0.6	1.53	1.87	0.172	0.428	2.16	1.62	1.62
GP0.15	0.4	0.6	1.53	1.87	0.172	0.428	3.25	2.43	2.43
GP0.2	0.4	0.6	1.53	1.87	0.172	0.428	4.33	3.25	3.25

Table 5 Experimental values

Mix designation	Weight of specimen casting (kg)	Slump (mm)	Weight at time of testing (kg)	Load at ultimate (kN)	Strength in compression (MPa)	Average compressive strength (MPa)
GF0	8.16	50	8.10	1435.52	63.80	59.93
	7.99	50	7.92	1275.9	56.71	
	8.09	50	8.02	1333.6	59.27	
GF0.1	8.13	30	8.06	1489.53	66.20	63.14
	8.10	30	8.02	1417.69	63.01	
	7.90	30	7.83	1354.55	60.20	
G0.15	8.12	25	7.95	1494.82	66.44	66.27
	8.29	25	8.05	1491.4	66.28	
	7.97	25	7.75	1486.75	66.08	
GP0.2	8.13	21	8.03	1591.31	70.72	67.74
	7.95	21	7.92	1495.56	66.47	
	7.89	21	7.81	1485.35	66.02	

4 Discussion on test results

Slump in the fresh stage overall, the information provided suggests that the study aimed to assess the performance of geopolymer concrete with graded glass fiber in terms of slump and compression strength. The results were compared with previous investigations, and the concrete mixes demonstrated a good degree of deformability based on the observed slump values.

4.1 Weight of specimens

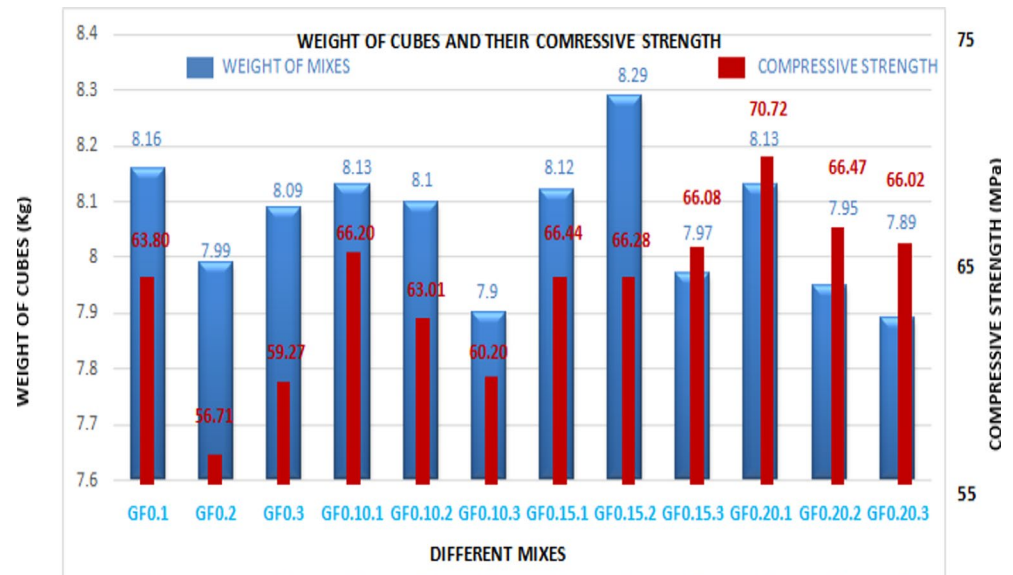
The weight of cubes in the control specimen should theoretically be lighter than the mixes with different volume fractions of fibers. This expectation arises from the higher specific gravity of fibers. As the volume fraction of fibers was varied from 0.1% to 0.2% of volume of concrete, this effect could not be noticed properly. This may be due to the fact that the specific gravity of fiber and other ingredients are nearly equal to 2.6 and the fiber addition is only 0.2% of volume of specimen. Higher weight of specimen at the time of testing indicates well packing of material and this provides an indication of lower porosity or interconnected voids which helps in resisting the more load. The weights of maximum cube specimens are more than 8.1 kg which indicates the density of geopolymer concrete is more than conventional concrete i.e. 2400 kg/m³. So, GPC is heavier than conventional concrete. The finding that higher weight correlates with higher compressive strength suggests that the distribution and packing of ingredients, including fibers, may play a role in the strength characteristics of the concrete. It's an interesting observation and could have implications for optimizing concrete mix designs. The cubes having weight 8.03 kg, 8.05 kg, 8.06 kg and 8.10 kg at the time of testing are found to have higher compressive strength as 70.72 MPa, 66.28 MPa, 66.20 MPa and 63.80 MPa respectively as in Fig. 4. The cube having weight of 7.83 kg at the time of testing is found to have lower strength of 60.20 MPa.

4.2 Workability

The study examined slump values in different concrete mixes, ranging from 20mm to 50 mm. Graded fiber mixes contained 40% of 9 mm, 30% of 12 mm and 30% of 20 mm fibers. Short-length fibers were added to arrest micro cracks and enhance toughness Kasagani et al. [21]. As fiber volume increased, slump value decreased due to fibers' arresting nature. This may be due to addition of fibers bridges the ITZ section and restricts the flow of mortar matrix. Mixes with higher fiber volume fractions showed a greater reduction in slump. The overall trend suggests that as fiber volume fraction increases, slump decreases, following a linear relationship with the control specimen.

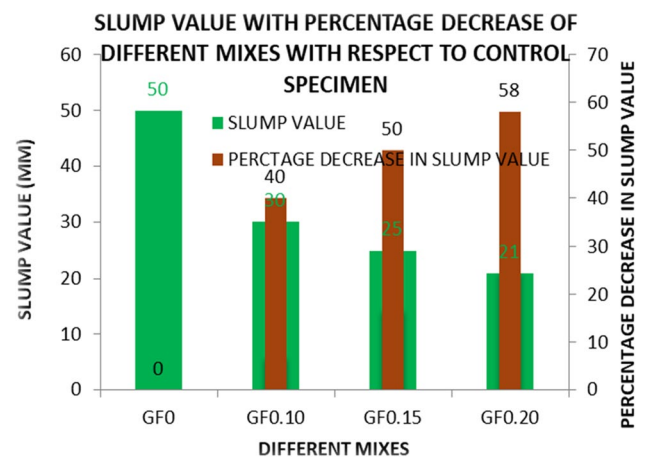
Due to higher fineness of GGBFS, reaction is faster than fly ash when added with activated alkali solution. To gain early high strength GGBFS, percentage was taken higher (60%) than fly ash (40%) in this investigation.

Fig. 4 Variation of weight of specimens with compressive strength



The value of fresh properties of different mixes was presented in Table 3. Slump value was noticed as varying from 20 mm to 50 mm. The same was observed by earlier researcher Vikash and Rao [24]. In all graded fiber mixes 9 mm fiber was added 40%, 12 mm 30% and 20 mm 30% of the total fiber amount. More percentage of short length fibers are added than long fibers as short length fibers are capable of arresting micro cracks and increases the toughness. With increase content of fiber volume, slump value was found to be decreasing due arresting nature of fibers with other ingredients. The control specimen GF0 was found to have slump 50 mm, while mixes GF0.10, GF0.15 and GF0.20 were found with slump values of 30 mm, 25 mm and 21 mm respectively. Mixes GF0.10, GF0.15 and GF0.20 were found to have 40%, 50% and 58% lower slump than control mix respectively. The mix with volume fraction 0.15 and 0.20 fiber volume exhibited 16.67% and 30% less slump respectively with respect to fiber volume 0.10. Specimen containing fiber volume 0.20 was found to have 16% less slump with respect to fiber volume 0.15. Fig. 5 presents value of slump and reduction of slump with control specimen GF0 to different mixes. Fig. 5 reveals that the percentage reduction in slump of different mixes varies linearly with respect to control specimen GF0. As the slump value decreases due to addition of increased fiber volume fraction, it creates a practical problem in construction field in placing and transporting the geopolymer concrete. For higher retention of slump, the plastic shear stress is to be reduced which can be done by adding super plasticizers. For increasing paste flow or for obtaining higher slump, the constant mixing can help in breakings the flocs which will help in reduction of shear stress of green geopolymer concrete. As the shear stress reduces, the workability also increases. As in the experimental program sodium silicate is used, it reduces the yield stress and helps in achieving proper [25]. Another solution for this problem may be addition of plasticizers.

Fig. 5 Slump value and percentage decrease in Slump value with respect to control specimen GF0



4.3 Compressive strength

The experimental compressive strength result and the graphical representation of the results indicate that both Fly ash and GGBFS have identical reactive constituents and the difference in their percentage is less. Literature reveals that GGBS play pivotal role in developing and workable and high strength mortar and concrete. Like fly ash, blending OPC with GGBFS is becoming popular in Asia and Europe where iron and steel extraction are plenty. Fly ash and GGBFS had specific gravities of 2.17 and 2.90, respectively.

The majority of the spherical fly ash particles are made up mostly of silica and alumina in significant amounts. The GGBFS granules have an angular, crystalline morphology. GGBS was found to have a higher concentration of calcium and silica in comparison to other components. The slag's calcium component raises basicity and boosts compressive strength power. X-ray mineral analysis was used to characterize the fly ash and GGBS sample mineralogically. GGBFS depicts glass content as 99%. Higher glass concentration contributes to increased hydraulic activity, which in turn quickens the process of polymerization.

The study found that the compressive strength of concrete specimens increased with an increase in fiber percentage, attributed to the presence of more short and long fibers in larger volume fractions. The addition of graded fibers increased compressive strength by 5.36%, 10.58%, and 13.3% over 56 days. However, the increase beyond 0.15% fiber volume fraction to 0.2 % was not as that of the increase in strength during the increase in fiber volume from 0.1% to 0.15%. This may be due to bulging of fibers when added in higher quantity. To find the optimum dosages of fiber more experimental investigation is required. The important quality of hardened concrete that affects other mechanical qualities of concrete is compression strength. In 56 days, it was discovered that the concrete specimens made with GF0, GF0.10, GF0.15 and GF0.20 had respective compressive strengths of 59.93 MPa, 63.14 MPa, 66.27 MPa, and 67.74 MPa. The same is plotted in Fig. 6 as per the experimental data of compression test conducted in CTM machine shown in Fig. 7. The figure reveals that increase in compressive strength is due to increase in fiber percentage in mixes. This may be because more short and long fibers were present in larger volume fractions of mixes, which were capable of arresting both macro and micro cracks. In comparison to the control specimen GF0, the addition of graded fibers of combinations of 9 mm, 12 mm, and 20 mm with volume fractions of fibers 0.1 %, 0.15 %, and 0.20% increased compressive strength by 5.36%, 10.58%, and 13.3%, respectively, during 56 days. The increase in compressive strength with volume fraction 0.20 over volume fraction 0.15 was 2.22% which shows increase in volume fraction of fibers beyond 0.15% cannot add much strength to the specimens as per the same enhancement rate when the fiber content is below 0.15%. The reason may be due to bulging of fibers when added in higher volume fraction. Kasagani and Rao [19, 20] noticed the reduction in strength of 0.4% fiber with respect to 0.3% fiber. Compressive strength ratio of 0.3% fiber to control specimen of 0% fiber was found to be 1.3 and the same for 0.2% fiber to control specimen of 0% fiber was 1.24. This proves rate of improvement of strength ceases beyond 0.2% fiber content. To draw a conclusion more research is required on addition of fibers for a volume fraction ranging 0% to 0.5%.

Fig. 6 Compressive strength Value of different mixes and percentage increase in strength w.r.t. fiber volume

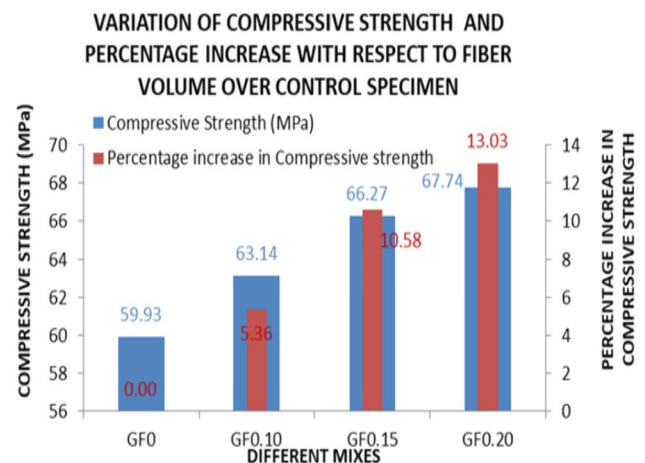


Fig.7 Compression test by CTM



5 Conclusion

The research was taken to ascertain the qualities of graded glass fiber geopolymer concrete. Slump value is calculated in fresh stage of concrete while strength in compression was tested at 56 days. From the above test results, the below mentioned conclusions are made.

1. Geopolymer concrete with graded glass fiber is produced from GGBFS and fly ash as binder rather than OPC contributing a green environment to human society.
2. GPC is heavier than conventional concrete.
3. Weight of cubes in control specimen (without fiber) have more weight than the mixes with different volume fraction fibers as specific gravity of fibers is lower than other ingredients.
4. Addition of graded fiber decreases workability due to arresting nature of fibers with concrete ingredients.
5. Mixes with volume fraction of graded fiber 0.10, 0.15 and 0.20 were found to have 40%, 50% and 58% lower slump than control mix (without fiber) respectively.
6. The mix with volume fraction 0.15 and 0.20 exhibited 16.67% and 30% less slump respectively with respect to fiber volume 0.10. Mix with fiber volume 0.20 was found to have 16% less slump with respect to fiber volume 0.15.
7. In a particular volume fraction of fiber, the cubes having higher weight exhibit higher compressive strength than other cubes may be due to proper packing.
8. Increase in compression strength is due to inclusion of graded fiber. 56 days compression strength reveals that there is increase of 5.36%, 10.58%, and 13.03% with the addition of graded fibers of volume fractions of 0.1, 0.15, and 0.20, respectively. Mixtures with volume fractions of 0.15 and 0.20 improved compressive strength over the specimen GF0.10 by 4.96% and 7.29%, respectively, in 56 days.

6 Future scope of research

The next step of research may include finding the optimum dosages of graded fiber along with determination of compressive strength of graded fiber GPC for higher ages of curing.

The other mechanical properties such as split tensile strength, flexural strength and modulus of elasticity may be taken up as future research area.

Flexural strength, split tensile strength and modulus of elasticity may be predicted in terms of compressive strength of graded fiber GPC and supported with experiential verification.

This can help to push the concrete with OPC to back seat, use of GGBFS and fly ash for production of GPC will be sustainable and more friendly.

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Data availability Data is provided within the manuscript and any data used during the study can be assessed when requested.

Declarations

Ethics approval and consent to participate All data generated or analysed during this study are included in this published article and any data used during the study can be assessed when requested.

Competing interests The authors declare no competing interests.

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