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# HIGH STRENGTH GEOPOLYMER CONCRETE INCORPORATING GGBS AS FILLER

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## ABSTRACT

*The high strength geopolymer concrete and its properties are evaluated by using ground granulated blast furnace slag. In this research fly ash replaced by ground granulated blast furnace slag and its percentage of replacement is 20%, 40%, 60%, 80% and 100% by the weight of flyash and its cured by ambient temperature. Using trial and error method to get M20 grade geopolymer concrete. The source materials physical properties are tested in material test laboratory. In this project fresh and harden concrete properties and durability properties are evaluated. The specimen casting, curing and the mechanical, durability, flexural performance evaluated. The slump results shows GGBS content increase similarly reduce the workability of concrete. the grade of geopolymer concrete is achieved M20 to M80. 100% GGBS blended GPC achieved M80 grade GPC. Similarly split tensile strength and modulus of rupture also increased due to GGBS. 100% GGBS blended GPC beam achieve optimum load carrying capacity and withstand more deflection compare to 100% flyash blended GPC beam. This project clearly proven flyash ash 100% replaced by GGBS mix achieved high strength geopolymer concrete.*

**Key Words :** *Compressive strength, Flexural strength, Geopolymer concrete, Ground granulated blast furnace slag, High strength; Slump, Split tensile strength, Sodium silicate.*

## 1. INTRODUCTION

Portland cement is a fairly common binding component in concrete because it to the strength and durability of it [1]. Because of this, cement is widely known for its quick enhancement of strength. It has certain detrimental effects on the environment during production since cement manufacturing, in particular, uses a lot of virgin raw materials, consumes a lot of energy, and produces greenhouse gases. Clay, lime stone, and calcium carbonate are the non-renewable raw materials used to make cement [2,3]. In actuality, the cement industry is in charge of 7% of the carbon

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dioxide emissions into the environment (Malhotra 2006) [4,5]. One tonne of Portland cement clinker manufacturing releases a same amount of $CO_2$ into the atmosphere, according to Kumar Mehta (2001)[6]. Humans consume Portland cement alongside water in the twenty-first century. India finished second in the world only to China in cement production. Consequently, there is a strong desire to make a brand-new, environmentally friendly binder [7].

This generated a number of studies and research projects that have been a project to partially replace cement with industrial waste materials. Despite the fact that industrial wastes are created in large quantities each year, only a small portion of them are used in construction projects, with the majority being dumped in landfills [8]. The preferred use of these materials helps protect the environment from global warming, promote sustainability, and prevent landfill waste. However, using cement's industrial by products to partially replace it did not result in a solution that would prevent the world from consuming cement. As a result, everyone in the globe is searching for the greatest cement substitute that can take the place of cement entirely. As a result, ongoing research is expanding globally. After extensive investigation, Davidovits was able to identify the geopolymer, a priceless new cementitious substance. Geopolymers were recognised by Davidovits as a capable inorganic adhesive.

Professor of Chemistry Davidovits came up with the idea for geopolymer concrete in 1978 after learning that a geopolymer matrix may be used in place of cement as a binding agent in concrete. According to Davidovits' theory, an alkaline solution can be added to a source material that is high in silica and aluminium to create a geopolymer binder [9]. A byproduct of the thermal power plant using coal is fly ash. It possesses a few advantageous physical and chemical characteristics. Low levels of calcium are present in fly ash. Fly ash indicates less loss during igniting. Fly ash is most frequently employed as a component in the creation of geopolymer concrete because of these qualities. Blast furnace slag, rice husk ash, natural alumino silicate minerals, and metakaolin are other additive materials that are high in silica and alumina. These materials can also be utilised in geopolymer concrete as a binder [10,11].

OPC is not used in the production of geopolymer concrete. The binder is the main distinction between geopolymer concrete and Portland cement concrete. To create the paste that binds the fine aggregate and coarse aggregate to make the geopolymer concrete, the alumina and silica in the low calcium fly ash react with the alkaline solution [12]. The fine and coarse aggregate make up about

75% to 80% of the bulk in geopolymer concrete, much like Portland cement concrete does. Similar to Portland cement concrete, geopolymer concrete also benefits from the angularity, grading, and strength of the particles. Therefore, the methodologies now accessible for Portland cement concrete can be used to build geopolymer concrete combinations.

Geopolymer exhibits an amorphous morphology and shares some chemical properties with zeolites. Alumino-silicate minerals are turned into a variety of building materials during geo-polymerization [13]. As a result, the new composition has amazing chemical and physical qualities like resistance to acid and fire. Three distinct procedures each include the geopolymerization reaction. Figure 1 depicts the natural Al-Si minerals that make up geopolymerization.

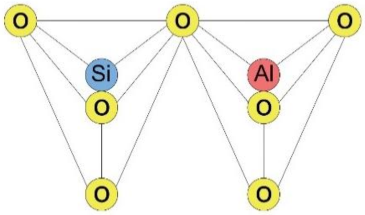

**Fig 1** Structure of geo-polymer concrete

All of these minerals are soluble in alkaline solution, with NaOH dissolving to a larger extent than KOH and silicates [14]. Minerals with a greater degree of dissolution have greater compressive strength after geopolymerization. The silicon and aluminium ions in the raw materials, such as fly ash, GGBS, silica fume, bentonite, etc., are dissolved in the alkaline solution during the initial mixing. Here, the water molecules are joined by an oxygen bond created by the condensation reaction of silicon and aluminium hydroxide. The oxygen connection that was created as a result of condensation links the nearby Si and Al tetrahedra. Figure 2 provides an accurate depiction of the reaction.

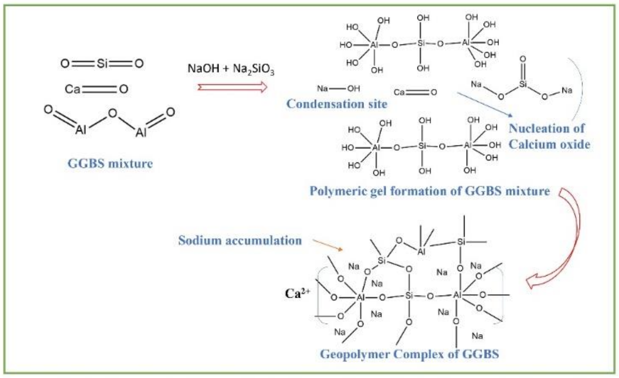

Figure 2. Geo-polymerization reaction

At high temperatures, this polymerization reaction occurs, Moreover, stronger geopolymers are produced [15]. At room temperature, GGBS added geopolymers can quickly harden and reach high compressive strength [16]. In this research fly ash replaced by ground granulated blast furnace slag and its percentage of replacement is 20%, 40%, 60%, 80% and 100% by the weight of flyash. The specimens are cured by ambient temperature. This research trial and error method used to get M20 grade geopolymer concrete.

## 2. MATERIALS AND METHODS

Low calcium fly ash (Class F) that complies with IS 3812 - 2003 was utilised for this experimental work and was obtained from the Mettur Thermal Power Station in Tamil Nadu, India. Large amounts of Class F fly ash are dumped as waste by Mettur Thermal Power Station, which pollutes the area. In order to make geopolymer concrete, an effort has been undertaken in this study to use this fly ash as a cementitious ingredient. Fly ash has a specific gravity of 2.46 and a fineness of 7.62. The particles are spherical in shape. Fly ash consists of finely divided ashes produced by pulverized coal in power stations. The chemical composition depends on the mineral composition of the coal gangue (the inorganic part of the coal). Silica usually varies from 40 to 60% and alumina from 20 to 30%.

Ground Granulated Blast furnace Slag (GGBS) (figure 3.3) which was confirming to with IS 12089-1987 was used as the secondary binder. When iron ore, limestone, and coke are burned to a temperature of roughly 1500°C in the furnace, GGBS is produced as an industrial byproduct. Mineral components including aluminates, silicates, calcium oxide, etc. are formed during the melting of slag. After grinding, the slag has a noncrystalline calcium alumina silicate content of 95%. The GGBS has some benefits, including improved strength and durability characteristics and a decrease in $CO_2$ emission. The specific gravity of GGBS is 2.9.

When silicon dioxide ($SiO_2$) and sodium oxides ($Na_2O$) combine in a variety of ratios and are heated together to create sodium silicate, the result is a solid (1100-1200$^{o}$C). Due to the fact that it resembles a gel-like liquid and is soluble in water, it is also referred to as water glass. Sodium silicate presents sodium oxide 14.73%, silica oxide 29.75% and water 55.52%. Specific gravity of sodium silicate is 1.39 and its molecular weight 184.04. By electrolyzing a solution of sodium chloride, sodium hydroxide is produced. At normal temperature, sodium hydroxides have a white, crystalline, odourless solid state. As they take in moisture from the air, it has a very corrosive tendency. When it is dissolved in water or neutralised with acid, it releases enough heat. Combustible substance can be ignited by this heat. Instead of waiting the customary 12 hours, the alkaline solution is made 6 hours in advance of being combined with other materials since the released heat is meant to hasten the polymerization reaction. The molecular weight of NaOH is 40, pH value is 12 to 14 and Molecular weight 40.

Fine aggregates are defined as those that pass through a 4.75 mm sieve but are retained at a 0.075 mm sieve. The River to Zone-II that complies with IS: 383-2016 was used as the fine aggregate in the current study. It was confirmed to be clean, inert, and free of silt, clay, and natural dust. The river sand specific gravity obtained from laboratory value is 2.60 , fineness modulus 2.79, bulk density is 1.74g/cc and water absorption, free moisture content values is 1.4%, 0.71%. Coarse aggregates are often defined as those that pass through a 20mm sieve. As the coarse aggregate in this study, locally accessible crushed rocks that had been put through a 20 mm filter were used. The coarse aggregate was properly cleaned to remove dust and other impurities before being dried under dry shell conditions and tested in accordance with IS 383-2016. A number of tests were performed, and the outcomes are listed. The river sand specific gravity obtained from laboratory value is 2.79, fineness modulus 5.74, bulk density is 1.67g/cc and water absorption value is 0.25%. For this study, a super plasticizer (CERAPLAST 300) was utilised. It is added to concrete as a chemical additive to improve workability. The entire research process in the lab uses water that is readily available nearby. The alkaline liquid is prepared by the same water. Fly ash replaced by GGBS 0%,20%, 40%, 60%, 80%,100%. The mix proportion of GPC achieved by using trial and error method. 6kg/m$^3$ superplasticizer used all the mixes to improving workability of geopolymer concrete.

**Table 1** Mix proportion for geopolymer concrete (kg/m$^3$)

| MIX | CA | M-Sand | Fly ash | GGBS | SS | SH | SP |
|---|---|---|---|---|---|---|---|
| **CM1** | 1170 | 630 | 400 | 0 | 142.86 | 57.14 | 6 |
| **M1** | 1170 | 630 | 320 | 80 | 142.86 | 57.14 | 6 |
| **M2** | 1170 | 630 | 240 | 160 | 142.86 | 57.14 | 6 |
| **M3** | 1170 | 630 | 160 | 240 | 142.86 | 57.14 | 6 |
| **M4** | 1170 | 630 | 80 | 320 | 142.86 | 57.14 | 6 |
| **M5** | 1170 | 630 | 0 | 400 | 142.86 | 57.14 | 6 |

The mechanical, durability and flexural properties of geopolymer concrete and GGBS blended geopolymer concrete are ascertained through experimental research on concrete cubes, cylinders, prism and beams. The IS 1199-1959-compliant concrete slump test determines the workability or consistency of the concrete mix. The slump test is a very straight forward method used to quickly assess the workability of concrete. Slump cone equipment is used to conduct the slump cone test. The cone that is utilised for the slump cone test is 30 cm tall, with bottom and top diameters of 20 cm and 10 cm, respectively. As shown in Figure 3, Three layers of the prepared concrete mix are added to the container, and each layer is tamped 25 times with the tamping rod. The top surface of the mould is levelled once it has been fully filled, and then it is carefully pulled upward and the droop is measured right away. The height difference between the mould and the concrete's highest point is used to calculate the slump value.

The majority of concrete's desirable characteristic qualities and the goal of structural design are qualitatively related to compressive strength, making it the most often performed test. In Figure 4, the test setup is depicted. The compressive strength of concrete cube is calculated by using equation, maximum load divided by cross section area of the cube. The test was conducted in CTM of capacity 2000 kN. The tensile strength of cylinders is calculated by the formula given below. In Figure 5, the test setup is depicted. The split tensile strength of concrete cylinder is calculated by using equation, 2 times the maximum load divided by 3.14 multiplied by length and diameter of cylinder. The 400 KN capacity universal testing machine used for the flexural strength test was used to perform the flexural test with two point loading. The Modulus of Rupture is the theoretical maximum tensile stress experienced in the test beam's bottom fibre. Due of the high stress placed on the extreme fibre in the prism during the two-point loading, any segment in the middle third of the prism length may experience a critical crack. Figure 6 depicts the test setup.

To find the flexural strength by the formula given below.
Flexural stress = $PL / bd^2$ for $a > 13.3$ cm
Flexural stress = $3Pa / bd^2$ for $a < 13.3$ cm
Where, P = Maximum load applied to the specimen in kN. L= Supported Length in mm. d = Depth of the specimen mm. a = Distance of the crack from the nearest support.

The durability test of control geopolymer concrete and GGBS blended geopolymer concrete is assessed by cubical specimen adopted for different environment. The concrete cubical specimens are immersed in water, magnesium sulphate, NaCl solution, HCl solution and also adopted in different temperature. After 28days the cubical specimens evaluated in weight loss and strength loss. Figure 7 to 10 shows the cubical specimens immersed in water, sulphate, salt and acidic solution.

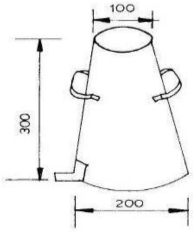

**Fig 3** Slump cone apparatus

**Fig 4** Testing of cubes in CTM

**Fig 5** Testing of cylinders in CTM

**Fig 6** Rupture of prism in flexure test

**Fig 7** Water absorption test

**Fig 8** Sulphate resistance test

**Fig 9** Salt resistance test

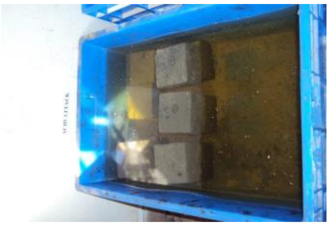

**Fig 10** Acid resistance test

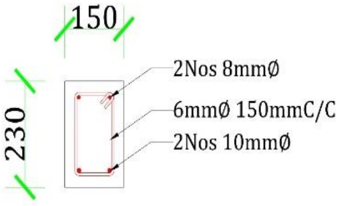

**Fig 11** HSGPC beam reinforcement details

The flexural behavior of control geopolymer concrete and high strength geopolymer reinforced concrete was verified and the experimental results were analyzed. For analysis, the flexural member size 1500 mm x 150 mm x 230 mm. Twelve beams in total were formed, There are two nos. of 10 mm diameter bars at the tension face and two nos. of 6 mm diameter bars at the compression face in the concrete samples. All of the beams were made out of 8 mm diameter steel at 150 mm c/c with two legged shear reinforcement. Figure 11 displays the thorough reinforcement. The manufactured reinforcement was put inside a wooden mould with the necessary cover. Both concretes were thoroughly mixed and poured into the appropriate beam moulds. After 24 hours, all beams were demolded, and all beams were left to cure for 28 days at ambient temperatures. The two point static loading system was used to test the beam specimens. The beams were tested using a hydraulic jack with a 100 kN capacity. Figure 12 displays the whole test configuration. Load was gradually applied, and an LVDT was used to record the corresponding deflection value for each load increment of 5 kN. The first fracture load was observed.

**Fig 12** Experimental test setup of High strength GPC flexural member

## 3. RESULTS AND DISCUSSION

All the high strength geopolymer concrete mixes adopted for slump cone test. The graphical representation of slump as shown in Figure 13. The amount GGBS increased cause workability of concrete reduced. The GGBS increased relatively compressive, split tensile and flexural strength also increased to achieve high strength geopolymer concrete. 100% GGBS based geopolymer concrete achieved M80 grade concrete.

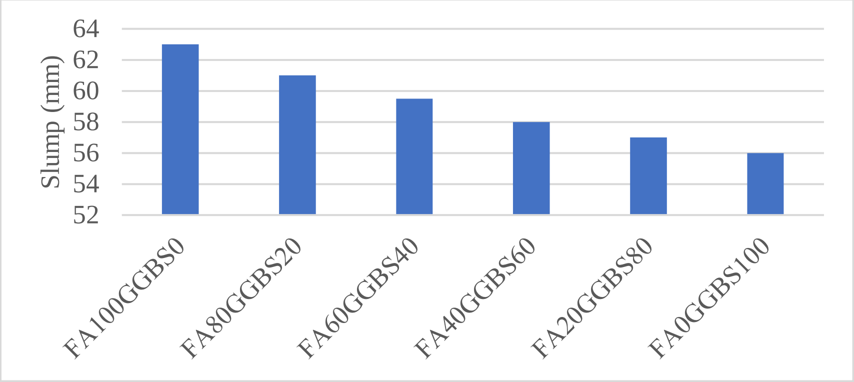

**Fig 13** Slump for high strength geopolymer concrete

**Table 2** Mechanical test results for high strength geopolymer concrete

| **Sl.No** | **Mix** | **% of GGBS** | **Compressive strength** | | **split tensile strength** | | **Flexural strength** | |
|---|---|---|---|---|---|---|---|---|
| | | | 7Days (MPa) | 28Days (MPa) | 7Days (MPa) | 28Days (MPa) | 7Days (MPa) | 28Days (MPa) |
| **1** | FA100GGBS0 | 0 | 10.10 | 24.50 | 0.98 | 2.37 | 0.85 | 2.07 |
| **2** | FA80GGBS20 | 20 | 21.30 | 35.40 | 2.06 | 3.42 | 1.80 | 2.99 |
| **3** | FA60GGBS40 | 40 | 40.00 | 53.40 | 3.86 | 5.16 | 3.38 | 4.52 |
| **4** | FA40GGBS60 | 60 | 56.85 | 68.24 | 5.49 | 6.59 | 4.81 | 5.77 |
| **5** | FA20GGBS80 | 80 | 64.85 | 74.95 | 6.26 | 7.24 | 5.48 | 6.34 |
| **6** | FA0GGBS100 | 100 | 72.54 | 80.34 | 7.01 | 7.76 | 6.13 | 6.79 |

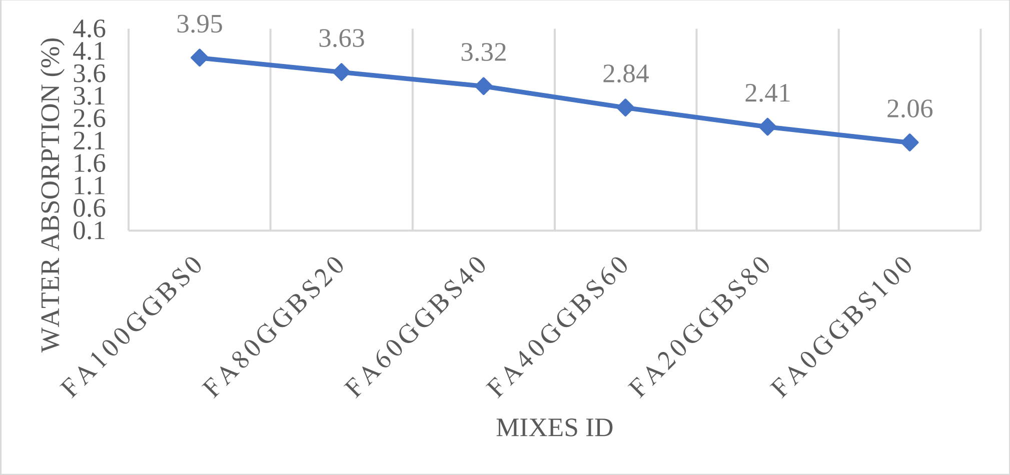

**Fig 14** Water absorption for high strength geopolymer concrete

Six type of geopolymer mixes adopted mechanical properties analysis. The mechanical properties of geopolymer concrete tested by universal testing machine. The compressive, split tensile and flexural strength of geopolymer concrete enhanced by GGBS. The compressive strength result shows 100% GGBS presented specimens achieved M80 grade concrete strength or 80.34N/mm$^2$. It will be 2.5times higher compare to 100% flyash presented specimens. The similar results are obtained in the split tensile strength and flexural strength. The mechanical test results are described in Table 2. The durability properties of high strength geopolymer concrete shown in Figures 14 to 23. The durability results shows that 100% flyash binder geopolymer concrete presents highest loss in weight and strength and 100% GGBS binder geopolymer concrete present lowest losses in weight and strength.

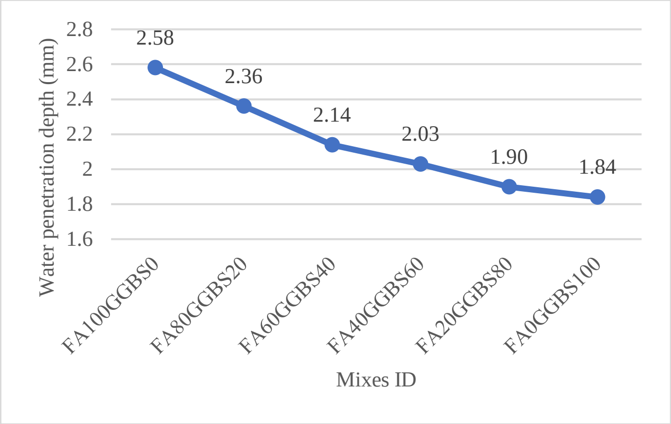

**Fig 15** Water penetration depth for high strength geopolymer concrete

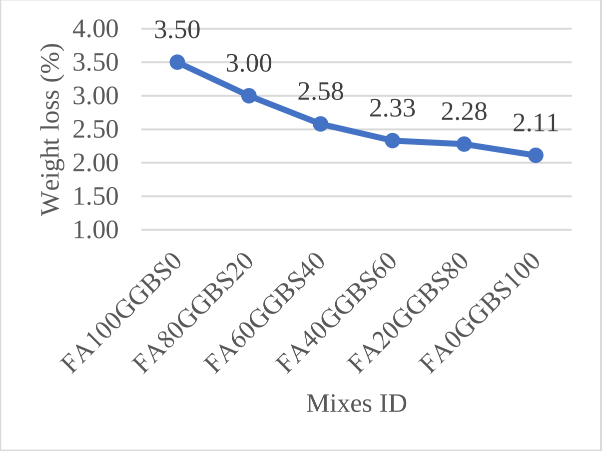

**Fig 16** Percentage of weight loss due to sulphate attack

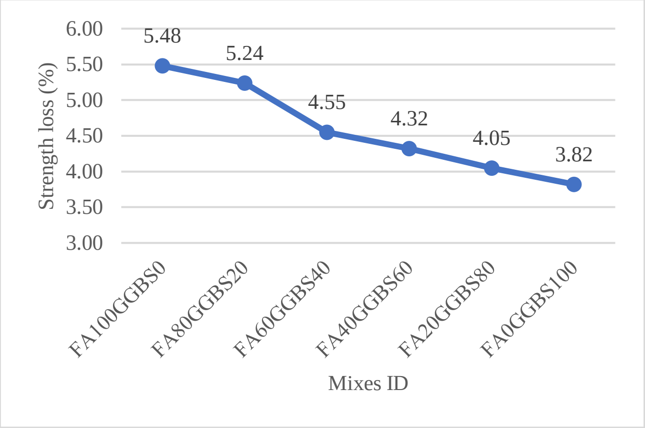

**Fig 17** Percentage of strength loss due to sulphate attack

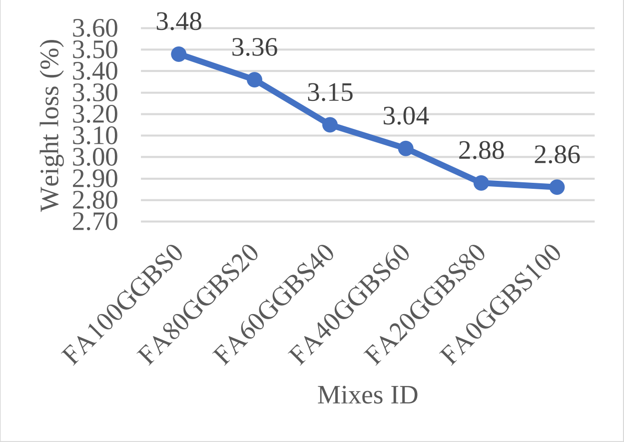

**Fig 18** Percentage of weight loss due to chloride attack

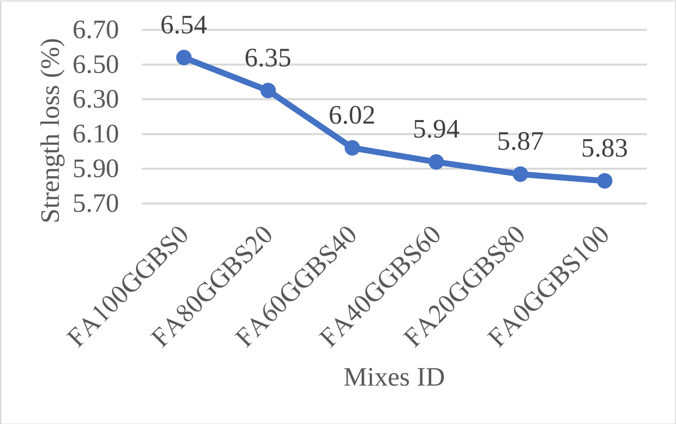

**Fig 19** Percentage of strength loss due to chloride attack

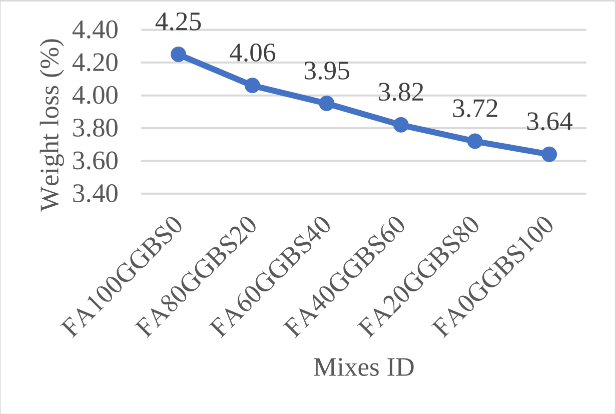

**Fig 20** Percentage of weight loss due to acid attack

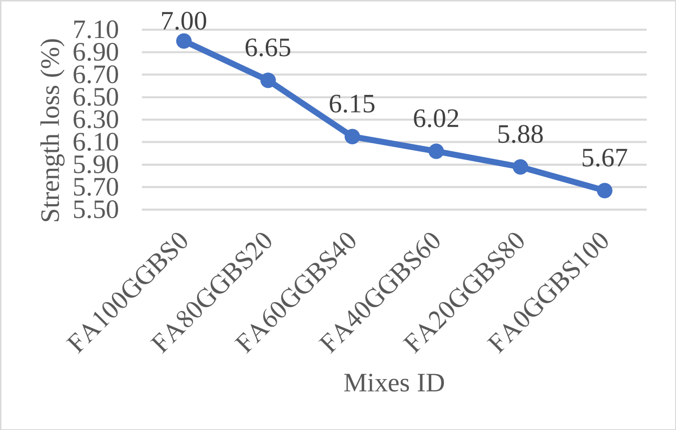

**Fig 21** Percentage of strength loss due to acid attack

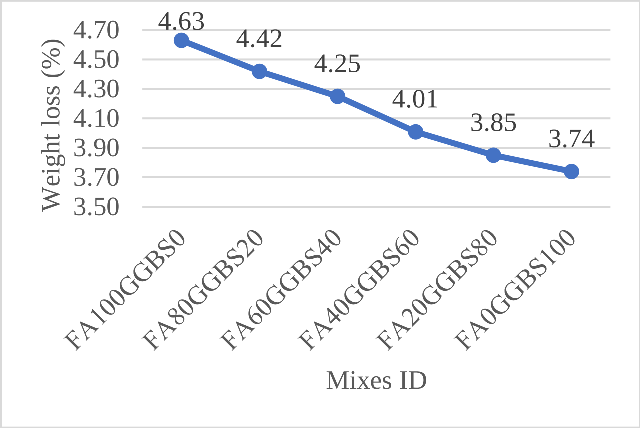

**Fig 22** Percentage of weight loss due to alkaline attack

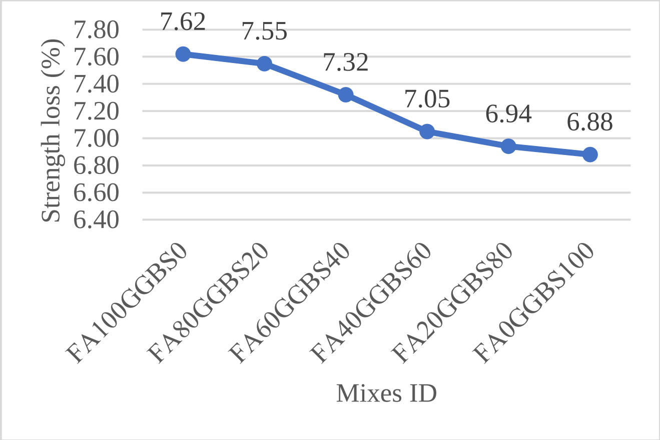

**Fig 23** Percentage of strength loss due to alkaline attack

The flexural member size of 1500mm × 150mm × 230mm casted in 100% fly ash and 100% GGBS mixes and tested in loading frame equipment. The experiment result of flexural member descried in Table 3. 100% GGBS blended geopolymer concrete beam achieved highest ultimate load and withstand more deflection compare to 100% flyash mix beam.

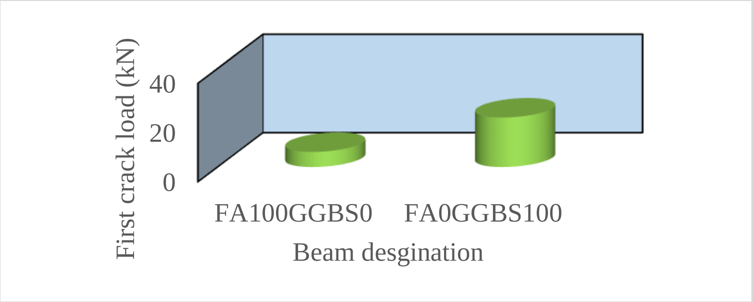

**Fig 24** First crack load for flexural member

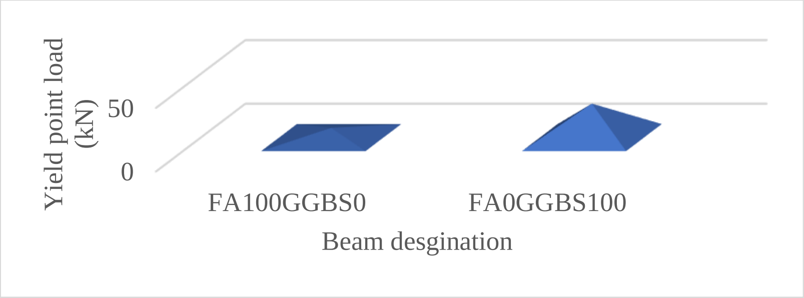

**Fig 25** Yield point load for flexural member

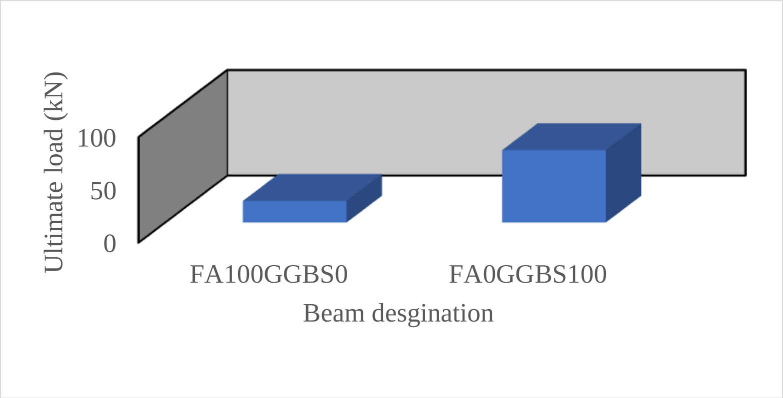

**Fig 26** Ultimate load for flexural member

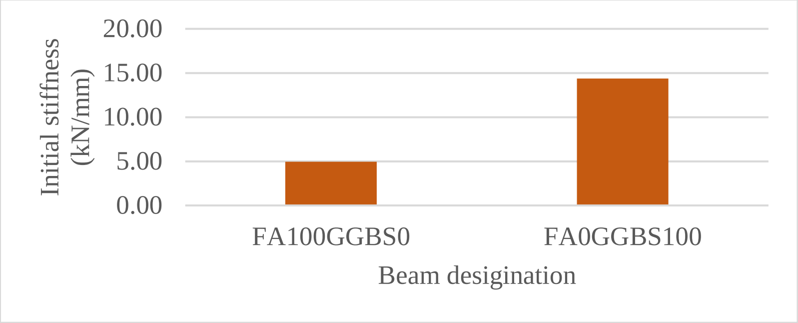

**Fig 27** Initial stiffness for high strength geopolymer concrete

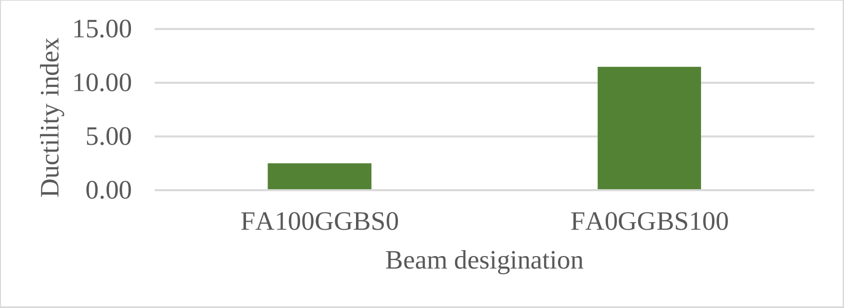

**Fig 28** Ductility index for high strength geopolymer concrete

The flexural member size of 1500mm × 150mm × 230mm casted in 100% flyash blended GPC and 100% GGBS blended GPC mixes and tested in loading frame equipment. The experiment result of flexural member descried in Table 3. 100% GGBS blended geopolymer concrete beam achieved highest ultimate load and withstand more deflection compare to 100% flyash blended GPC beam. the ductility index and stiffness also enhanced by GGBS. 100% fly ash blended geopolymer concrete achieved lowest first crack load, yield load and ultimate load and the value is 6.125kN, 7.684kN, and 20.502kN. The 100% GGBS blended geopolymer concrete is achieved highest first crack load, yield load and ultimate load.

## 4. CONCLUSION

GGBS amount increased similarly workability of concrete reduced. Compressive strength of geopolymer concrete is achieved high strength geopolymer concrete. 100% GGBS based geopolymer concrete M80 grade strength achieved in 28days of ambient curing. Split tensile strength and flexural strength are increased by GGBS. Durability behaviours improved by GGBS content. Flyash replaced by GGBS amount increased at the time strength loss and weight loss also reduced. Geopolymer concrete made very dense in structure. 100% Fly ash based geopolymer concrete beam achieved lowest ultimate load and deflection. 100% GGBS based geopolymer concrete beam achieved highest ultimate load and withstand more deflection.

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