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Experimental study on Flyash and Ground Granulated Blast Furnace Slag on the Strength of Geopolymer concrete

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Abstract: ***Concrete is one of the most used construction materials nowadays. Portland cement makes up the majority of concrete. The main material that doesn't use Portland cement or emit greenhouse gases is geopolymer. Davidovits (1978) suggested the geopolymer approach as a potential replacement for Portland cement in concrete. In order to make binders, he suggested polymerising alkaline liquids with silicon and aluminium obtained from geological sources or byproducts like fly ash, slag, and rice husk ash. He called these binders "geopolymers". The most likely sources of geopolymers are fly ash and slag. The mechanical, long-term, and microstructural characteristics of geopolymer concrete made from fly ash and powdered granulated blast furnace slag are investigated in this study. This study examines the effects of different ratios of ground granulated blast furnace slag (GGBS) and class F fly ash (FA) on the durability and mechanical properties of geopolymer concrete (GPC). Alkaline activators include NaOH and*** Na_2SiO_3***. The bond, compressive, split tensile, and flexural strengths were examined in this study. We also examined tests for sulphate attack, rapid chloride permeability, and water absorption using geopolymer concrete composed of ground granulated blast furnace slag and low-calcium fly ash. These values were measured at room temperature after 7, 28, 56, and 90 days of cure. A previous work (Hardjito and Rangan, 2005) provided the GPC mix proportions used in this experiment. The short-term mechanical, long-term durability, and microstructural properties of GPC mixes made of FA and GGBS were investigated in this work. The short-term mechanical durability and micro-level variations between GPC and M45-grade regular concrete were also examined in this study. Fibre-reinforced geopolymer concrete has been studied by researchers. The strength and durability of various geopolymer concrete mixtures have been evaluated.***

Keywords: Fly ash (FA), ground granulated blast furnace slag (GGBS), Na_2SiO_3***, NaOH, bond, compressive, split tensile, and flexural strengths.***

I. INTRODUCTIONS

The geopolymer technology, which has great potential for usage in the concrete industry as a substitute for Portland cement as a binder, was initially introduced by Davidovits in 1978. It's crucial to remember that this possibility has a lot of promise. The possibility that the geopolymer technology might cut carbon dioxide emissions into the atmosphere by around 80% is one important step that could be taken to lessen the effects of global warming. These pollutants are produced by businesses in the aggregate and cement sectors. They are composed of fly ash and ground granulated blast furnace slag, sometimes referred to as FA and GGBS, respectively. They mix with a very acidic solution during the repolymerisation process. The binding substance is created as a consequence of this process. Its constituent parts are silicon, or Si, and aluminium, or Al. The recently created substance called 'geopolymer concrete' may serve as a binder without Portland cement.

The cement industry uses a lot of energy when compared to other sectors. The manufacture of Portland cement requires four gigajoules of energy per tonne, which is more energy-intensive than the production of steel and aluminium. The process that uses the most energy is the production of Portland cement. As a result, Portland cement production is the cement industry's most energy-intensive operation. India's cement industry is the nation's third-largest coal user, behind thermal power plants and the iron and steel industry. The nation's largest coal user is the iron and steel industries. A significant quantity of fly ash (FA) is produced by thermal power plants. As a result, there are certain disposal issues. Only a little more than half of all activities conducted by the government, a few non-governmental organisations, and research and development institutes use FA. India now produces 130 million tonnes of FA annually; by 2012, this amount is predicted to have increased to 175 million tonnes. FA was effectively used as a mineral addition component in the manufacturing of Portland pozzolana-mixed cement. That was almost sixty years ago. We have effectively used this tactic. The use of FA in the production of cement concrete is advantageous since it reduces the amount of pollutants released into the environment while also offering technical benefits. As a result, using FA is an effective strategy. Instead of using Portland cement as a binder for making concrete, this experiment uses a geopolymer made of fly ash and low calcium. To get the intended outcomes, this is done. We take this action in order to achieve our goals. The fly ash-based geopolymer paste is in charge of binding the loose coarse aggregates, fine aggregate sand, and other ingredients that haven't yet experienced any chemical reactions together while making geopolymer concrete. Admixtures may continue to be present or absent throughout this process. The manufacturing method for geopolymer concrete involves the use of standard techniques used in the concrete technology field. GPCs are able to combine any of these methods in a special manner. As part of their investigation, conducted trials with GPCs that were cured at room temperature. The compressive strength of structural grade GPCs, which ranges from 20 to 70 MPa, was thoroughly investigated and analysed by the researchers. A thorough analysis of these materials' mechanical and durability characteristics was done. Additionally, do research on the usage of GPC materials in building blocks and pavers.

II. MATERIALS AND METHODS

Furthermore, a number of the cementitious elements that are essential to the GPC structure are absent from the concrete. These elements are not part of the concrete. Conventional Portland concrete's increased strength is occasionally attributed to the process of cement hydration, which is frequently in charge of this development. 8 and 9. Hydration does not occur during this experiment because GPC cementitious materials cannot react with water. The cementitious ingredients, which are very rich in silica and alumina, go through a chemical process called polymerisation to achieve the required amount of strength in concrete. The purpose of this process is to increase the durability of concrete. According to the notion, polymerisation is the process by which monomer molecules combine to form polymeric chains, which may be two-dimensional or three-dimensional. This interaction might occur in a number of ways. Alkaline liquids serve as catalysts for the polymerisation of GPC within the limitations of this system. The two main components of the GPC manufacturing process are cementitious materials and alkaline liquids that serve as catalysts. Each part is in charge of performing its own special function. These minerals might be byproducts of businesses like GGBS, FA, or SF, or they could be naturally occurring minerals like kaolinite or clay. The source materials might alternatively be a combination of the two; we believe that both categories of materials have practical uses. Depending on the circumstances, either an alkaline beverage based on potassium or sodium may help achieve this. Furthermore, it is possible that they are a complete hybrid of the two types.

A. Materials

Class F fly ash and GGBS were the raw materials for geopolymer concrete employed in this experiment. This is true even though a wide variety of raw ingredients may be used to make geopolymer concrete. Another interesting feature is that, similar to OPC, the aggregates made up between 75 and 80 per cent of the concrete's total mass. The components that go into making GPC will be examined in the sections that follow. The components' physical and chemical characteristics are covered in this section. The elements are discussed in reference to these attributes. Fly ash, ordinary Portland cement (53 grade), fine and coarse aggregate, ground granulated blast furnace slag and alkaline liquids.

Figure 1: Typical constituents of a GPC

Table 1: Specific gravity of materials

Materials	Specific Gravity
Cement	3.15
Fly ash	2.12
GGBS	2.92
Fine aggregate	2.62
Coarse aggregate	2.58
Steel fiber	7.5

B. Mix design

We selected the following ratios for the components of the combinations based on a modest previous investigation on GPC. 77% of the concrete's total mass is made up of aggregate mass, which consists of both tiny and coarse particles. The activator solution's mass ratio to fly ash and GGGGBS falls between 0.3 and 0.4. The ratio is 0.35, according to our calculations. Sodium hydroxide and sodium silicate solutions have mass ratios between 0.4 and 2.5. For the majority of the mixes, the ratio was fixed at 2.5 since the sodium silicate solution is much less expensive than the sodium hydroxide solution. The molarity of the sodium hydroxide (NaOH) solution was maintained at 10 M and determined the water to geopolymer solids ratio. We added a lot of water. For our comparison research, we determined the M45 grade of conventional concrete (CC). After making sure there was enough slump, El fibres were added to the mix in different quantities (0.25, 0.5, 0.75, and 1.0% by volume of concrete).

III. RESULTS AND DISCUSSIONS

Summary of the findings and observations about the mechanical and durability characteristics. This chapter also includes the findings. Tables, bar charts, and graphical representations are used to illustrate the findings of the current research study, which examines compressive strength, split tensile strength, and bond strength. The assessment focused on the material's strengths. The data from the water absorption test is shown in a table, while the results from the fast chloride permeability test are illustrated in a bar chart. We analyse the data at each phase of the experimental process. This is executed to enhance the clarity of the analysis. This interpretation of the results required an examination of both the data's attributes and the literature's insights. The findings' importance is an asset, and it is crucial to examine the requirements outlined by the appropriate prior mix design.

This study primarily focuses on a geopolymer formulation suitable for curing in standard ambient conditions, using low-calcium fly ash (Class F), sometimes referred to as GGBS, as the main source of aluminosilicate binder. The fundamental purpose of this inquiry is the design and development of this geopolymer combination. This study aims to examine how different factors of the combination affect the properties of mixes that are made without heat curing. These features include the setting time, ease of manipulation, and early-age compressive strength. This study investigates the effects of ambient-cured fly ash-based geopolymer concrete on concrete properties. Special emphasis is placed on the mechanisms by which concrete may fracture and bond to itself. The objective in manufacturing geopolymer concrete is to establish a method for ascertaining the suitable proportions of GGBS and a blend of low-calcium fly ash. A study examination will be conducted to examine the impact of ground granulated blast furnace slag on geopolymer concrete. The below enumeration delineates the many types of geopolymer concrete materials: To generate geopolymer concrete, we amalgamate GGBS with hardened low-calcium fly ash. This study aims to assess the engineering characteristics present in the short term. The qualities include, but are not limited to, flexural strength, bond strength, split tensile strength, and compressive strength. This inquiry aims to examine the durability characteristics of geopolymer concrete via the use of RCPT, water absorption, and acid tests. This experiment aimed to investigate the impact of varying the concentration of the alkaline activator solution on geopolymer concrete. In this experiment, the molar concentration of the hydroxide solution examined was 10 M.

This experiment aimed to investigate the impact of varying the concentration of the alkaline activator solution on geopolymer concrete. In this experiment, the molar concentration of the hydroxide solution considered was 10 M. This approach aims to examine the link between the split tensile strength and the compressive strength of geopolymer concrete samples generated with different amounts of fly ash and ground granulated blast-furnace slag across diverse time periods. Additionally, we want to assess the cost of one cubic metre of CC (M45) at the 28-day compressive strength and juxtapose it with comparable goods. This study examines the mechanical properties and long-term durability of fibre-reinforced geopolymer composites via various combinations. We assessed the influence of fibres at concentrations of 0.25 per cent, 0.50 per cent, 0.75 per cent, and 1 per cent on several mechanical properties and durability metrics using diverse GPC combinations. Flexural strength, split tensile strength, and compressive strength exemplify mechanical properties. Additional instances encompass splitting tensile strength. To assess durability characteristics, we conducted the RCPT, water absorption, and acid attack tests. All mandated tests were conducted by us. All tests were conducted in compliance with the applicable requirements. We examine the experimental findings to establish a correlation between the split tensile strength and compressive strength of geopolymer concrete produced with varying proportions of fly ash (FA) and ground granulated blast-furnace slag (GGBS), cured for different durations.

A. Compressive strength

All mixes' cubical specimens were tested for compressive strength after 7, 28, 56, and 90 days of curing. Once the mixes cured, this was done. This was done to assure IS 516 (1991) compliance. Three 150-by-150-by-150-millimetre cubical samples were cast and examined for each age and combination. Three cubical samples were cast. Samples were analysed to identify their characteristics. These specimens underwent numerous scientific tests and castings. The specimen's compressive strength, f'c, was estimated by dividing its maximum load by its cross-sectional area. It created the compressive strength sign. We measured the specimen's compressive strength this way.

Table 3: Compressive strength of CC and GPC

Mechanical property	**Age**	**Mix type**					
		M45	**FA0-GGBS100**	**FA25-GGBS75**	**FA50-GGBS50**	**FA75-GGBS25**	**FA100-GGBS0**
Compressive strength pc (MPA)	7	26.12	54.29	51.11	35.30	13.30	10.51
	28	51.39	60.23	58.12	46.32	15.55	12.11
	56	54.23	63.11	59.02	48.33	28.22	18.68
	90	56.34	65.23	62.32	51.78	33.02	22.03

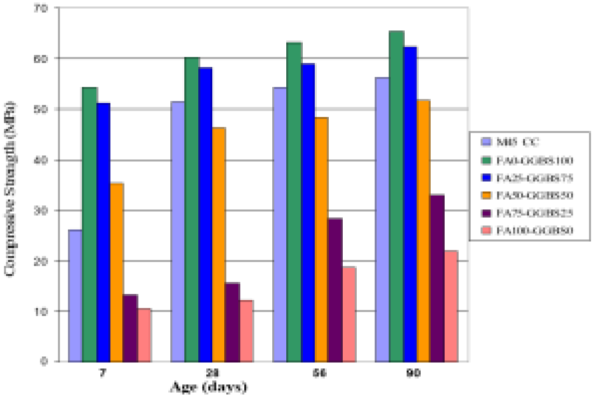

Figure 2: Compressive strength versus Age the various proportions of FA: GGBS

Seven days of cure gives typical concrete 26.12 MPa of compressive strength. After seven days, geopolymer concrete with FA:GGBS ratios of 0:100, 25:75, and 50:50 had higher compressive strengths than normal concrete. However, ordinary concrete with FA:GGBS:75:25 and FA:GGBS:100:0 mix proportions has lower compressive strength.

Figure 2 demonstrates how FA/GGBS ratio and cure time affect geopolymer concrete compressive strength. Figure 3 shows that geopolymer concrete compressive strength decreases with FA content. This is true regardless of concrete curing time. We also found that a certain fraction of the mixture rises in compressive strength with age. We proved it. M45 grade CC has 26.12 MPa compressive strength after seven days of curing. Fig. 3 shows a 60:40 FA:GGBS blend. Determined this percentage. To maintain geopolymer concrete compressive strength, we must utilise this ratio. M45 grade CC has 51.39 million pounds of compressive strength after 28 days of curing. We calculated geopolymer concrete's FA: GGBS mix fraction from the curve (Fig. 3). This proportion must be used to produce compressive strength. M45 CC has 54.23 MPa compressive strength after 56 days of curing. FIG. 3 shows a 35:65 FA:GGBS mix for geopolymer concrete. We consider this %. See theessive power below. After curing M45 grade CC for 90 days as required, we measured 56.34 MPa compressive strength. We calculated geopolymer concrete's FA:GGBS:38:62 mix percentage from Fig. 3. This dish suited us well. Our percentage must meet compressive strength. Geopolymer concrete has maximum compressive strength. Without considering healing time, we explain the FA:GGBS ratio of 0:100. We compare the compressive strength of geopolymer with regular concrete from the same age. We call the reference mix standard concrete. Polymer concrete grew 107.8%, 17.2%, 16.3%, and 15.7% at 7, 28, 56, and 90 days. Between days 7, 28, 56, and 90, increases occurred. The following table shows these percentage increases for your evaluation. After seven days of curing, compressive strength increased, as seen in the table. Compression strength of geopolymer concrete We also found that this rate decreases with surface area. Studies also show that FA concentration lowers GPC compressive strength, even without cure. Research also shows that the mix's compressive strength increases with age. Recent research confirms this. Comparing FA0-GGBS100 to M45 CC showed its higher compressive strength for all ages. M45-grade sustainable concrete should use an FA0-GGBS100 mix percentage.

B. *Split tensile strength*

After 90 days of curing, all mixtures were tested for splitting tensile strength (STS). International Standard 5816 (1999) was followed. We cast three 150 mm x 300 mm cylindrical examples and rigorously tested them to evaluate each age group and blend. We steadily raised the weight until the specimen broke at capacity. This lasted until the specimen broke. We recorded the maximum load for future reference. We measured the specimen's length and cross-section. The splitting tensile strength (fct) was calculated using the following formula:

Table 4: Split tensile strength of CC and GPC

Mechanical property	**Age**	**Mix type**					
		M45	**FA0-GGBS100**	**FA25-GGBS75**	**FA50-GGBS50**	**FA75-GGBS25**	**FA100-GGBS0**

Split tensile strength (MPA)	7	2.23	2.46	2.54	1.84	1.273	1.132
	28	3.44	3.56	3.23	2.06	1.362	1.160
	56	3.51	3.82	3.32	2.47	1.485	1.182
	90	3.59	4.06	3.54	2.68	1.67	1.32

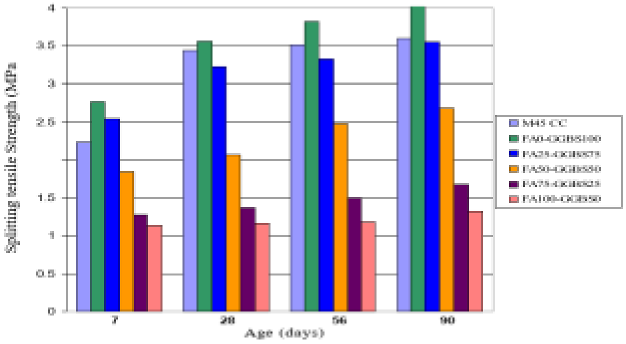

Figure 3: variation split tensile strength with age the various proportions of FA: GGBS

CC M45 split tensile strength was 2.23 MPa after seven days of curing. From the graph (Fig. 3), we determined geopolymer concrete's FA: GGBS: 36:64 mix proportion. The analysis showed this. This % gives the same split tensile strength.

After 28 days of curing, M45 construction concrete had 3.44 MPa split tensile strength. Fig. 4 shows that FA: GGBS: 11:89 is the best mix percentage. Geopolymer concrete needs this proportion for split tensile strength. After 56 days of curing, grade M45 construction concrete had 3.51 MPa split tensile strength. The geopolymer concrete mix % FA: GGBS is 16:84, calculated from the graph (Fig. 4). The analysis showed this. This option has the same split tensile strength.

The split tensile strength of grade M45 commercial concrete after 90 days of curing was 3.59 megapascals. Fig. 4 shows that FA: GGBS: 21:79 is the best mix percentage. Geopolymer concrete needs this proportion for split tensile strength.
Geopolymer concrete has the highest split tensile strength possible. For 0:100 FA:GGBS, independent of cure duration. We compare the split tensile strength of geopolymer concrete with normal concrete at the same age. [13,14] Two strengths define this comparison. Consider standard concrete as the reference mix. After 7, 28, 56, and 90 days, geopolymer concrete's split tensile strength increases 23.76%, 3.48%, 8.83%, and 13.09%. These figures are higher than previous ones. Geopolymer concrete split tensile strength improves fastest after seven days of cure. This rate slows with concrete age. No matter the time. GPC split strength decreases with FA content, regardless of cure time. We've seen this. Studies show that split strength rises with age, even when mix quantity stays constant. Even when the mix is consistent, this happens. FA0-GGBS100 has better split tensile strength than M45 CC regardless of age. Regardless of age, this is always true. M 45 sustainable concrete should use FA0-GGBS100 mix %. This advice is supported by the findings.

C. *Bond strength*

Bond strength test was conducted on the specimens for all the mixes after 7,14 and 28 days of curing as shown in Table 5. The specimen of size 1m TMT bar was placed horizontally placed in center of cube. The specimens were cast and tested for each age and each mix.

Table 5: Bond strength of CC and GPC

Mechanical		**Mix type**

property	Age	M45	FA0-GGBS100	FA25-GGBS75	FA50-GGBS50	FA75-GGBS25	FA100-GGBS0
Bond Strength MPa	7	8.95	12.48	10.77	10.43	9.21	4.47
	14	10.99	13.85	12.59	11.15	8.88	6.39
	28	14.37	16.78	15.22	13.33	10.9	8.23

The bond strength of M45 grade CC was 10.99 MPa after 14 days of curing. The mix proportion of FA:GGBS for geopolymer concrete is 51:59, determined from Table 5. The analysis showed this. To get the same binding strength, this value is desired.

The bond strength of M45 grade CC after 28 days of curing is 14.37 MPa. Geopolymer concrete has a 39:61 FA: GGBS mix percentage from the graph (Fig. 5.6). This proportion was reasonable. To acquire the same bond strength, use this percentage. Geopolymer concrete has the maximum bond strength possible. When FA to GGBS is 0:100, the condition is given without considering cure time. The bond strength of geopolymer concrete is compared to normal concrete at the same age. This comparison determines geopolymer concrete's efficacy. Note that the reference mix is regular concrete. After seven, fourteen, and twenty-eight days, geopolymer concrete bond strength rose 39.5%, 26.02%, and 16.77%. This was determined using bond strength measurements. After seven days of cure, geopolymer concrete bond strength increases quicker and decreases with age. This is backed by various research. When FA is added to the mixture, GPC binding strength diminishes. This happens independent of curing time. Even when the mix fraction remains the same, binding strength increases with age. This applies even with the same combination. Research shows that FA0-GGBS100 regularly outperforms M45 CC in bond strength. No matter how ancient the mixed material, this stays true. M45 sustainable concrete should use an FA0-GGBS100 mix percentage. This advice is supported by the findings.

D. Flexural strength

To providing support for the specimen, the bed of the testing machine must be equipped with two steel rollers that have a diameter of 38 millimetres. It is necessary to set these rollers in such a way that the distance between the centres of specimens measuring 15.0 cm and 10.0 cm is either 60 cm or 40 cm, respectively, according to the specimen's dimensions. The load will be applied by two rollers that are like one another and are situated at the third places of the supporting span, which is either 20 or 13.3-centimetres centre to centre. The load must be distributed uniformly between the two loading rollers, and each roller must be positioned in such a way that the load is supplied axially and without placing the specimen under any torsional stresses or limitations.

Table 6: Flexural strength of CC and GPC

Mechanical property	Age	Mix type					
		M45	FA0-GGBS100	FA25-GGBS75	FA50-GGBS50	FA75-GGBS25	FA100-GGBS0
Flexural Strength MPA	7	2	3.4	3.1	2.1	1.9	1.6
	14	3.15	3.9	4.1	3.8	3.1	2.9
	28	3.3	5.59	5.51	5.35	4.9	3.3

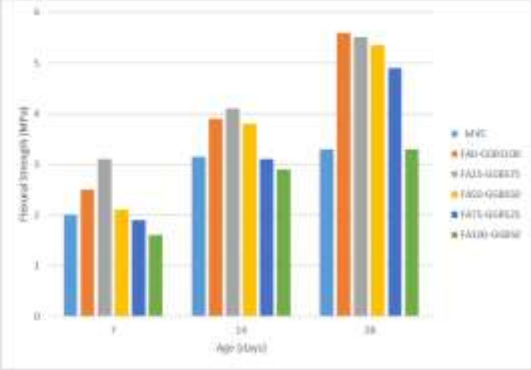

Figure 4: Flexural strength with age the various proportions of FA: GGBS

Geopolymer concrete has the maximum flexural strength possible. We explain the FA:GGBS ratio of 0:100, disregarding curing time. We compare the flexural strength of geopolymer concrete with normal concrete at the same age. This comparison evaluates geopolymer concrete's efficacy. We consider the reference mix regular concrete. Flexural strength increases 0.6%, 0.5%, and 0.71% in geopolymer concrete at 7, 14, and 28 days. Each interval shows this rise. This increment occurs at each time point. There is evidence that geopolymer concrete flexural strength increases more slowly with ageing. Geopolymer concrete's flexural strength increases quicker after seven days of cure. FA levels significantly decrease GPC flexural strength, even without cure. We've seen this. Research shows that flexural strength improves with age, even when mix amount stays constant. This applies even with the same combination. Research shows that FA0-GGBS100 has stronger flexural strength than M45 CC. Regardless of age, this is always true. M45 sustainable concrete should use an FA0-GGBS100 mix percentage. This advice is supported by the findings. This is why GPC mixes with more GGBS increased flexural strength more at all ages than those with solely FA-based GPCs. This was true independent of the experiment stage.

IV. CONCLUSIONS

As FA concentration rises, geopolymer concrete compressive and split tensile strengths decline. This damage depends on concrete curing time. For a given mix %, split tensile and compressive strengths increase with age. The mix proportions of FA:GGBS:0:100 provide geopolymer concrete the highest compressive and split tensile strengths independent of curing time. The compressive and split tensile strengths of geopolymer concrete grow rapidly after seven days of curing, but they decline as the concrete ages. Geopolymer concrete has a much higher binding strength than ordinary concrete made using standard components. The bond strength of geopolymer concrete is around one-third of its compressive strength. No matter how long geopolymer concrete cures, increasing FA in the mix decreases binding strength. As geopolymer concrete matures, its binding strength rises.

The proportion of water absorption in geopolymer concrete decreases with additional GGBS, although it depends on curing time. No matter how much GGBS is in the mixture, water absorption decreases with curing time. According to the RCPT, an FA:GGGBS:0:100 geopolymer concrete combination produces thick, less porous concrete. When compressive strength is measured after 28 days, GPC (FA39-GGBS61) costs 32% more than CC (M45 from the start).

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