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Experimental Investigation of Strength and Durability Performance on Geopolymer Concrete using Industrial Waste Material

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Abstract:** Concrete is one of the most used construction materials nowadays. Portland cement is the major ingredient in concrete. The main factor that does not require Portland cement or emit greenhouse gases is geopolymer. The geopolymer technique described by Davidovits (1978) as an alternative to Portland cement in concrete shows promise. He suggested polymerising alkaline liquids with silicon and aluminium in geological sources or byproducts like fly ash, slag, and rice husk ash to make binders. He called these binders geopolymers. Geopolymers are most likely to come from fly ash and slag. So, this study looks at the mechanical, long-term, and microstructural properties of geopolymer concrete made from fly ash and ground granulated blast furnace slag. This project investigates how different amounts of class F Fly Ash (FA) and Ground Granulated Blast Furnace Slag (GGBS) change the mechanical and long-lasting properties of geopolymer concrete (GPC). Alkaline activators include Na_2SiO_3 and NaOH. This study examined the compressive, split tensile, bond, and flexural strengths. We also explored water absorption, rapid chloride permeability, and sulphate attack tests using low-calcium fly ash and ground granulated blast furnace slag-based geopolymer concrete. These parameters were measured at ambient room temperatures after 7, 28, 56, and 90 days of cure. This research looked at the short-term mechanical, long-term durability, and microstructural properties of GPC mixtures made from FA and GGBS. This study also evaluated short-term mechanical, durability, and micro-level GPC to M45 grade ordinary concrete. Fibre-reinforced geopolymer concrete has been studied. Different geopolymer concrete mixtures have been tested for mechanical and durability. Fibres were added to concrete at 0.25%, 0.5%, 0.75%, and 1.0% by volume. We tested the compressive, split tensile, and flexural strength of fibre-containing mixtures after 28 days. Similar mixtures' RCPT, water absorption, and acid attack have been tested.

Keywords:** Geopolymer concrete (GPC), Class F Fly Ash (FA), Ground Granulated Blast Furnace Slag (GGBS), Na_2SiO_3 and NaOH, Compressive, Split tensile, Bond, Flexural strengths, Water absorption, Rapid chloride permeability, Sulphate attack.

I. INTRODUCTIONS

Davidovits (1978) was the first person to present the geopolymer technology, which has a tremendous amount of promise for use in the concrete industry as an alternative for Portland cement as a binder. It is important to note that this prospect offers a substantial amount of potential. One significant step that might be taken to mitigate the consequences of global warming would be the likelihood that the geopolymer technology may reduce the amount of carbon dioxide emissions that are released into the atmosphere by around 80 percent. Companies in the cement and aggregate industries are the ones responsible to produce these pollutants. Fly ash and ground granulated blast furnace slag, often known as FA and GGBS, respectively, are the raw ingredients that they are made of. During the process of repolymerization, they combine with a solution that is very acidic. As a result of this procedure, the binding material is produced. Silicon, also known as Si, and aluminium, often known as Al, are the components that are used in it. There is no need for Portland cement for the newly developed material known as geopolymer concrete to function as a binder [1, 2].

Compared to other industries, the cement sector has a relatively high energy consumption. Only the production of steel and aluminium is more energy-intensive than the manufacturing of Portland cement, which uses four gigajoules of energy per tonne of energy. The manufacturing of Portland cement is the most energy-intensive operation. Because of this, the process of producing Portland cement is the most energy-intensive one in the cement business. After thermal power plants and the iron and steel sector, the cement industry in India is the third-largest consumer of coal in the country.

The industry that produces iron and steel is the one that consumes the most coal in the country. Thermal power plants are the ones that are accountable for the generation of a considerable amount of fly ash (FA) [3]. Because of this, there are a few problems with disposal. In the context of operations carried out by the government, several non-governmental organisations and research and development institutions, the utilisation of FA is only slightly more than half of the total. There are now 130 million tonnes of FA that are produced yearly in India, and it is expected that by the year 2012, this quantity would have climbed to 175 million tonnes altogether. When it came to the production of Portland pozzolana mixed cement, FA was used as a mineral addition component in an efficient manner. That was more than sixty years ago. We have used this strategy in an efficient manner. This approach of employing FA in the manufacturing of cement concrete is beneficial since it simultaneously provides technical advantages while simultaneously reducing the quantity of pollutants that are emitted into the environment. Because of this, the use of FA is a method that is successful [4].

To this experiment, a geopolymer comprised of fly ash and containing low levels of calcium is used as a binder in the production of concrete rather than Portland cement. This is done to get the desired results. We do this to accomplish what we have set out to do [5]. To producing geopolymer concrete, the fly ash-based geopolymer paste is responsible for the following task: it is responsible for holding the loose coarse aggregates, fine aggregate sand, and other components that have not yet undergone any chemical reactions together. During this procedure, there is a possibility that admixtures will remain missing or present. When it comes to the production of geopolymer concrete, the manufacturing process entails the use of the conventional procedures that are utilised in the technological area of concrete [7].

GPCs can create a unique mixture of any of the ways. GPCs that were cured at room temperature were the subject of experiments that were carried out by [1] as part of their study. The researchers conducted an extensive study and analysis on the compressive strength of structural grade GPCs, ranging from 20 to 70 MPa. When it comes to the mechanical and durability properties of these materials, a comprehensive examination was carried out. Furthermore, have out research on the use of GPC materials in the production of pavers and construction blocks [6].

II. MATERIALS AND METHODS

Additionally, the concrete does not have several of the cementitious components that are an integral part of the GPC construction. As far as the concrete is concerned, these components are not included. The process of cement hydration, which is often responsible for the growth in strength, is sometimes credited as being the cause of the increase in strength that is produced in conventional Portland concrete. 8 and 9 Due to the fact that GPC cementitious materials are incapable of reacting with water, hydration does not take place throughout this experiment. In order to reach the necessary level of strength in concrete, the cementitious elements, which are very rich in silica and alumina, are subjected to a chemical process that is known as polymerisation. This procedure is carried out on concrete in order to improve its durability levels.

It is stated in the concept that polymerisation is the process by which monomer molecules join with one another in order to produce polymeric chains that may be either two-dimensional or three-dimensional. There is a variety of possible methods in which this contact might take place. In the constraints of this system, alkaline liquids perform the function as catalysts for the polymerisation of GPC. Cementitious materials and alkaline liquids that perform the function of catalysts are the two primary elements that make up the GPC manufacturing process. Every component is responsible for carrying out its own unique role. It is possible that these minerals are naturally occurring, such as kaolinite or clay, or that they are by-products of industries such as GGBS, FA, or SF. It is also possible for the source materials to be a blend of the two. [10, 11]; It is our opinion that both groups of materials have applications in the real world. This may be accomplished with the assistance of either a sodium- or potassium-based alkaline beverage, depending on the specifics of the situation. In addition to this, there is the possibility that they are a hybrid of the two sorts in their entirety.

A. Materials

The present experiment used Class F fly ash and GGBS as the source materials for geopolymer concrete. This is even though geopolymer concrete may be created using a broad range of source materials. As an additional point of interest, the aggregates constituted between seventy-five and eighty percent of the overall mass of the concrete, which is comparable to the situation with OPC. In the following sections, we shall investigate the constituent components that are used in the manufacturing of GPC. This section discusses the chemical and physical properties of the components. These qualities are discussed in relation to the constituents. Fly Ash, Ground Granulated Blast Furnace Slag, Fine aggregate, Coarse aggregate, Alkaline liquids, Ordinary Portland cement (53 grade). [20, 25]

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

Based on the small prior study on GPC [19],we chose the following ratios for the combinations' elements. Aggregate mass, which includes both coarse and small particles, makes up 77% of the total mass of the concrete. The mass ratio of the activator solution to fly ash and GGGGBS ranges between 0.3 and 0.4. We have determined the ratio to be 0.35. The mass ratio of sodium hydroxide solution and sodium silicate solution ranges from 0.4 to 2.5. Because the sodium silicate solution is much less costly than the sodium hydroxide solution, the ratio was set at 2.5 for most of the mixes. We kept the sodium hydroxide (NaOH) solution's molarity at 10 M. and found the ratio of water to geopolymer solids. We added water in large quantities. [21,24], we established the M45 grade of conventional concrete (CC) for our comparative analysis. El fibres were added to the mix in varying amounts (0.25, 0.5, 0.75, and 1.0% by volume of concrete) after sufficient slump had been ensured.

III. RESULTS AND DISCUSSIONS

Summary of the results and comments on the mechanical and durability properties. This chapter also contains the findings. Tables, bar charts, and graphical representations are used to present the results of the current research project, which focuses on compressive strength, split tensile strength, and bond strength. It was determined that the examination focused on the material's strengths. The information from the water absorption test is shown in the form of a table, and the information from the rapid chloride permeability test is shown in its own bar chart. We interpret the data at every stage of the experimental work. This is done to make the analysis more comprehensible. This interpretation of the findings required considering both the data's characteristics and the literature's information. The significance of the results is an asset, and it is important to consider the needs that were specified by the proper previous mix design.

A geopolymer combination that is appropriate for curing in normal ambient settings and that makes use of low-calcium fly ash (Class F), also known as GGBS, as the principal source of aluminosilicate binder is the primary focus of this research. The design and development of this geopolymer combination is the investigation's primary objective. The purpose of this research is to investigate the ways in which various parameters of the combination have an impact on the characteristics of mixes that are produced without the use of heat to harden them. These characteristics include the amount of time it takes for it to set, how simple it is to work with, and the compressive strength it has at an early age. An investigation of the impact of ambient-cured fly ash-based geopolymer concrete on the characteristics of concrete is carried out in this research. Particular attention is paid to the ways in which concrete may shatter and adhere to itself. To producing geopolymer concrete, the goal is to provide a technique for determining the appropriate quantities of GGBS and a combination of fly ash with a low calcium content. An investigation of the influence that ground granulated blast furnace slag has on geopolymer concrete is going to be carried out via research investigation. The following is a list of the several varieties of geopolymer concrete materials: In order to produce geopolymer concrete, we combine GGBS with low-calcium fly ash that has been hardened. The purpose of this research is to evaluate the engineering features that it has in the near term. These attributes include, but are not limited to, flexural strength, bond strength, split tensile strength, and compressive strength. Utilising RCPT, water absorption, and acid tests, the purpose of this investigation is to investigate the features of geopolymer concrete that pertain to its durability.

The purpose of this experiment was to study the effects that altering the concentration of the alkaline activator solution has on geopolymer concrete. In this experiment, the molar ratio of the hydroxide solution that was taken into consideration was 10M.

The purpose of this experiment was to study the effects that altering the concentration of the alkaline activator solution has on geopolymer concrete. During this experiment, the molar ratio of the hydroxide solution that was taken into consideration was 10M. The purpose of this technique is to investigate whether there is a correlation between the split tensile strength and the compressive strength of geopolymer concrete samples that were produced using varying proportions of FA and GGBS and for varying durations of time. Furthermore, we want to evaluate the cost of a single cubic meter of CC (M45) at the 28-day compressive strength and compare it to other similar products. This work investigates the mechanical and long-term durability characteristics of fibre-reinforced GPCs using a wide range of different combinations. Using a variety of different GPC combinations, we have evaluated the impact of fibres at concentrations of 0.25 percent, 0.50 percent, 0.75 percent, and 1 percent on a wide range of mechanical qualities and durability parameters. Flexural strength, split tensile strength, and compressive strength are all examples of mechanical qualities. Other examples include splitting tensile strength. As part of our efforts to collect information on the durability qualities, we carried out the RCPT, water absorption, and acid attack tests. Every test that was required was carried out by us. Every test was carried out in accordance with the particular standards that were relevant. By looking at the results of the experiments, we try to find a link between the split tensile strength and compressive strength of geopolymer concrete that was made with various amounts of FA and GGBS and was left to cure for various lengths of time.

A. *Compressive Strength*

The compressive strength of the cubical specimens of all of the mixes was assessed in line with the criteria after 7, 28, 56, and 90 days of curing. This was done after the mixtures had been allowed to cure. [22] This was done in order to ensure that it was in accordance with the requirements of IS 516 (1991). Three cubical samples, each measuring 150 millimetres by 150 millimetres by 150 millimetres, were cast and inspected for each age and each combination. In all, there were three samples cast as cubical samples. Analyses were performed on the samples to determine their characteristics. Scientific tests and casts were performed on these specimens at various points in time. The compressive strength of the specimen, which is represented by the symbol f'c, was calculated by dividing the maximum load that was applied to the specimen by the cross-sectional area of the specimen. This produced the compressive strength symbol. We used this technique to determine the specimen's compressive strength.

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

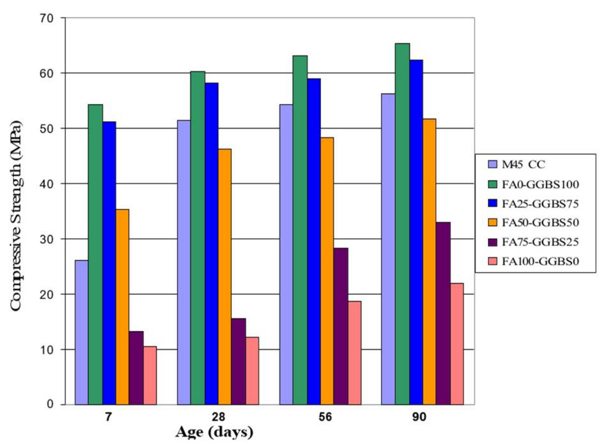

Figure 2: Compressive strength versus Age the various proportions of FA: GGBS

Typical concrete has a compressive strength of 26.12 MPa after seven days of curing. After setting for seven days, geopolymer concrete containing FA:GGBS:0:100, FA:GGBS:25:75, and FA:GGBS:50:50 exhibits stronger compressive strengths compared to regular concrete. Conversely, conventional concrete with mix proportions of FA: GGBS: 75:25 and FA: GGBS: 100:0 has lower compressive strength values than conventional concrete.

Figure 2 shows how the FA to GGBS ratio and cure time affect the compressive strength of geopolymer concrete. The compressive strength of geopolymer concrete goes down as the amount of FA in the mix goes up, as shown in Figure 3. No matter how long it takes for the concrete to cure, this remains the case. Additionally, we have demonstrated that the compressive strength of the mixture increases with age for a specific percentage of the combination. We have shown this. We found the compressive strength of M45 grade CC to be 26.12 MPa after allowing it to cure for seven days. The mix percentage of FA: GGBS is 60:40, as shown in the graph (Fig. 3). We determined this proportion. We must use this ratio to ensure the same compressive strength in geopolymer concrete. Following a 28-day curing period, the compressive strength of M45 grade CC is measured to be 51.39 million pounds. By examining the curve (Fig. 3), we were able to calculate the FA: GGBS mix proportion for geopolymer concrete. We must apply this percentage to achieve the desired compressive strength. The CC of M45 grade exhibits a compressive strength of 54.23 MPa after 56 days of curing. The graph (Fig. 3) indicates that the mix proportion of FA: GGBS for geopolymer concrete is 35:65. We take this percentage into consideration. Essive power is shown below. We measured a compressive strength of 56.34 MPa after curing CC of M45 grade for 90 days in accordance with the requirements. Based on the graph (Fig. 3), we determined the mix proportion of FA: GGBS:38:62 for geopolymer concrete. This recipe seemed the most suitable for us. We must use a proportion that matches the compressive strength. Geopolymer concrete achieves the highest possible level of compressive strength. When the FA ratio Without taking the curing time into consideration, we explain the scenario in which the ratio of FA to GGBS is 0:100. We conduct a comparison between the compressive strength of geopolymer concrete and traditional concrete, both produced at the same age. We regard the reference mix as standard concrete. At 7, 28, 56, and 90 days, the growth rates of polymer concrete were 107.8%, 17.2%, 16.3%, and 15.7%, respectively. Between days 7, 28, 56, and 90, these increases took place. The following table displays these percentage increases for your review. The table demonstrates the rate of increase in compressive strength over a seven-day curing time. The geopolymer concrete's compressive strength Additionally, we have shown that as the surface area grows, this rate progressively drops. Additionally, studies indicate that the GPC compressive strength decreases as the FA concentration increases, even in the absence of curing. Furthermore, research has shown that when the mix ages, a certain percentage of its compressive strength rises. Recent findings have verified this. A comparison between the FA0-GGBS100 blend and M45 CC demonstrated its superior compressive strengths for all ages. When building M45-grade sustainable concrete, we advise utilising the mix proportion FA0-GGBS100.

B. Split Tensile Strength

A splitting tensile strength (STS) test was performed on the specimens for all of the mixes after they had been cured for a period of ninety days. This was done in line with the International Standard 5816 (1999). To assess each age group and mix, we cast three cylindrical specimens measuring 150 mm x 300 mm and subjected them to rigorous testing. We gradually increased the weight until the specimen broke, reaching its full capacity. [23] This continued until the specimen shattered. We then documented the maximum load for future reference. We not only measured the specimen's length but also its cross-section. An application of the following formula was carried out in order to determine the splitting tensile strength (fct):

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

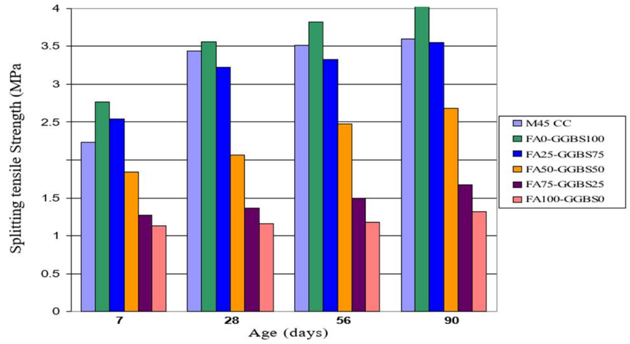

Figure 3: variation split tensile strength with age the various proportions of FA: GGBS

After allowing the material to cure for seven days, the split tensile strength of CC in the M45 grade was approximately 2.23 MPa. We calculated the mix percentage, FA: GGBS: 36:64, for geopolymer concrete from the graph (Fig. 3). This was the result of the analysis. To achieve the same split tensile strength value, use this percentage.

The split tensile strength of building concrete in the M45 grade was 3.44 MPa after it had been allowed to cure for a period of 28 days. The graph (Fig. 4) indicates that the most appropriate mix proportion is FA: GGBS: 11:89. In geopolymer concrete, this fraction is needed to achieve the same split tensile strength.

The split tensile strength of building concrete of grade M45 was 3.51 MPa after it had been cured for a period of 56 days. The graph (Fig. 4) led to the calculation of the mix percentage FA: GGBS for geopolymer concrete, which is 16:84. This was the result of the analysis. You can use this alternative to achieve the same split tensile strength value.

The split tensile strength of commercial concrete of grade M45 was 3.59 megapascals after it had been cured for a period of ninety days. The graph (Fig. 4) indicates that the most appropriate mix proportion is FA: GGBS: 21:79. In geopolymer concrete, this fraction is needed to achieve the same split tensile strength.

Split tensile strength is at its greatest conceivable level in geopolymer concrete, which is the highest attainable level. For the FA:GGBS ratio of 0:100, regardless of curing time. We compare the split tensile strength of geopolymer concrete with that of regular concrete at the same age. [13,14] The two strengths determine this comparison. One thing that should We consider the reference mix to be normal concrete. When geopolymer concrete's split tensile strength values are checked after 7, 28, 56, and 90 days, they go up by 23.76%, 3.48%, 8.83%, and 13.09%, respectively. When compared to the values that came before, these values are greater. After seven days of curing, the split tensile strength of geopolymer concrete increases more quickly than at any other time. This rate slows down as the concrete ages. This is the case regardless of the time. The split strength of GPC decreases with FA content, even without considering cure time. We have observed this phenomenon. Furthermore, studies have demonstrated that the split strength increases with age, even when the mix amount remains constant. Even when the mix remains constant, this phenomenon persists.

Regardless of the material's age, the mix FA0-GGBS100 has consistently achieved higher split tensile strength values compared to M45 CC. It makes no difference how old the substance is; this is always the instance. We recommend using a mix percentage of FA0-GGBS100 for the construction of the M 45 grade of sustainable concrete. The obtained results justify this recommendation.

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 property	Age	Mix type					
		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

After being allowed to cure for a period of fourteen days, the bond strength of CC on the M45 grade was determined to be 10.99 MPa. When it comes to geopolymer concrete, the mix proportion FA: GGBS that was calculated from the table 5 is FA: GGBS: 51:59. This was the result of the analysis. To get the same degree of bond strength, this is the value of bond strength that is sought.
The bond strength of CC of M45 grade with a curing duration of 28 days is 14.37 MPa after the curing time has passed. When it comes to geopolymer concrete, the mix proportion FA: GGBS that was derived from the graph (Fig. 5.6) is 39:61. This is the percentage that was found to be appropriate. This is the proportion that must be used to get the same bond strength value as before. Bond strength is at its greatest conceivable level in geopolymer concrete, which is the highest attainable level. When the ratio of FA to GGBS is 0:100, without taking into consideration the amount of time needed for curing, the situation is described. The bond strength of geopolymer concrete is compared to the bond strength of conventional concrete at the same age. This comparison is carried out to establish the effectiveness of the geopolymer concrete. One thing that should be brought to your attention is that the reference mix is normal concrete. We found that the bond strength values of geopolymer concrete increased by 39.5%, 26.02%, and 16.77%, respectively, after seven, fourteen, and twenty-eight days. This was established by the measurement of the bond strength values. The rate of increase in bond strength of geopolymer concrete has been shown to be much faster after a curing period of seven days, and this rate declines with increasing age. This is a finding that has been supported by several studies. Furthermore, it has been shown that the binding strength of GPC decreases when the quantity of FA in the mixture increases. This phenomenon occurs regardless of whether the curing time is considered. It has also been shown that the binding strength grows with age, even when the proportion of the mix stays the same. This is the case even when the mix is the same. Research demonstrates that FA0-GGBS100 consistently achieves higher bond strength values compared to M 45 CC. It makes no difference how old the blended substance is; this situation remains the same. We recommend using the mix percentage of FA0-GGBS100 for the construction of the M45 grade of sustainable concrete. The obtained results justify this recommendation.

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

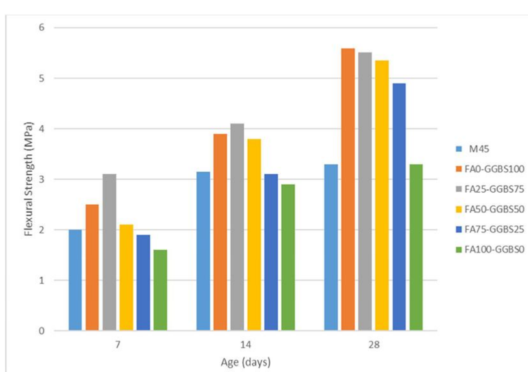

Figure 4: Flexural strength with age the various proportions of FA: GGBS

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Flexural strength is at its greatest conceivable level in geopolymer concrete, which is the highest attainable level. We describe the situation when the ratio of FA to GGBS is 0:100, excluding the curing time. We compare the flexural strength of geopolymer concrete to that of conventional concrete at the same age. We conduct this comparison to determine the effectiveness of geopolymer concrete. You should note that we consider the reference mix to be normal concrete. In geopolymer concrete, the percentage rise in flexural strength values is 0.6%, 0.5%, and 0.71%, respectively, at 7, 14, and 28 days. This increase occurs at each of these time intervals. It is at each of these time points that this increase takes place. There is evidence that this rate of increase in the flexural strength of geopolymer concrete slows down with age. Also, the rate of increase in the flexural strength of geopolymer concrete is much faster after seven days of curing. Flexural strength of GPC has also been seen to go down as FA levels rise in the mix, and this is true even when the curing period is not considered. We have observed this phenomenon. Research also demonstrates that the flexural strength increases with age, even when the mix quantity remains unchanged. This is the case even when the mix is the same. Research demonstrates that the blend FA0-GGBS100 consistently achieves higher flexural strength values than M 45 CC. It makes no difference how old the substance is; this is always the instance. We recommend using the mix percentage of FA0-GGBS100 for the construction of the M45 grade of sustainable concrete. The obtained results justify this recommendation. Because of this, at all ages, the increase in flexural strength was much greater in GPC mixes that had more GGBS than those that only had FA-based GPC. There was no difference in this respect, regardless of the stage the experiment was in.

E. Water Absorption

Following 28, 56, and 90 days of curing, we evaluated the water absorption of cylindrical specimens that measured 100 mm by 50 mm. We conducted tests in accordance with ASTM C 642-97. For every age group and combination, three test specimens were cast and put through a thorough testing process. Following each curing process, the specimens were dried for 24 hours at 1100 degrees Celsius in an oven. After the products were oven-dried, we noted their weight (W1). Following oven drying, we immersed these test specimens in water and weighed them every twelve hours (W2). We repeated this procedure for a minimum of 48 hours to ensure similar readings. We used the following formula to determine the substance's water absorption:

$$\text{Water absorption (\%)} = [(W_2 - W_1) / W_1] \times 100.$$

Table 7: Water absorption values of GPC and CC

Mix type	Age (days)	Water absorption (%)
FA0- GGBS100	28	1.23
	56	0.78
	90	0.56
FA25- GGBS75	28	1.52
	56	1.13
	90	0.94
FA50- GGBS50	28	2.03
	56	1.69
	90	1.47
FA75- GGBS25	28	2.90
	56	2.60
	90	2.48
FA100- GGBS0	28	3.72
	56	3.48
	90	3.38
M 45	28	3.13
	56	2.83
	90	2.69

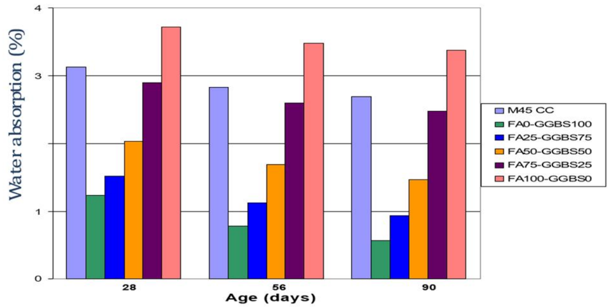

Figure 5: water absorption of mixes

The proportion of water absorption in geopolymer concrete changes with age, as seen in Figure 6. A bar chart illustrates this variance. This diversity is shown by several distinct FA: GGBS proportions. Furthermore, Figure 6 shows the change in the percentage of water absorption that occurs over time for normal concrete in the form of a bar chart. No matter how old the concrete is, researchers discovered that geopolymer concrete with the following proportions absorbs less water than ordinary concrete: FA: GGBS: 0:100, FA: GGBS: 25:75, FA: GGBS: 50:50, and FA: GGBS: 75:25. Regardless of the previously stated proportions, this was the reality. The illustration clearly demonstrates this concept. Regular concrete and geopolymer concrete, with a mix fraction of FA: GGBS: 0:100, exhibit significantly different water absorption rates. This circumstance occurs in each of the four proportions that were previously addressed. However, regardless of the concrete's age, the graph clearly shows that geopolymer concrete with a mix percentage of FA: GGBS: 100: 0 absorbs more water than ordinary concrete. Regardless of how old the concrete is, this is true. No matter how long the concrete has been there, this remains true. When compared to other mixes and traditional concrete, the percentage of water absorbed by geopolymer concrete with a mix proportion of FA: GGBS: 0: 100 after 90 days is low. This is due to the mix's relatively low FA: GGBS: 0: 100 percentage. It is hence the preferred material for making geopolymer concrete.

F. Rapid Chloride Permeability test

The Rapid Chloride Permeability Test (RCPT) employed 100 mm x 50 mm cylindrical specimens. We cured these specimens for 28, 56, and 90 days. Each age group and combination underwent rigorous testing on three cast test specimens. An "RCPT" cell assembly contains two components and is airtight and waterproof. The cathode compartment uses a three-percent sodium chloride solution, whereas the anode compartment uses sodium hydroxide. Next, 60V from a DC power supply was applied between the anode and cathode for RCPT on concrete samples. We achieved this goal. The current is measured every 30 minutes for up to six hours until it peaks.

Table 8: RCPT values of GPC and CC

Mix type	Age (days)	Charge passed (Coulombs)	Chloride penetrating rate
FA0- GGBS100	28	1302.6	Low
	56	1081.5	Low
	90	973.8	Very low
FA25- GGBS75	28	1448.1	Low
	56	1225.8	Low
	90	1130.4	Low
FA50- GGBS50	28	1665.3	Low
	56	1455.3	Low
	90	1379.4	Low
FA75- GGBS25	28	2069.4	Moderate
	56	1871.1	Low
	90	1778.7	Low
FA100- GGBS0	28	2946.0	Moderate
	56	2765.7	Moderate
	90	2675.7	Moderate
M 45	28	2424.6	Moderate
	56	2169.0	Moderate
	90	1924.5	Low

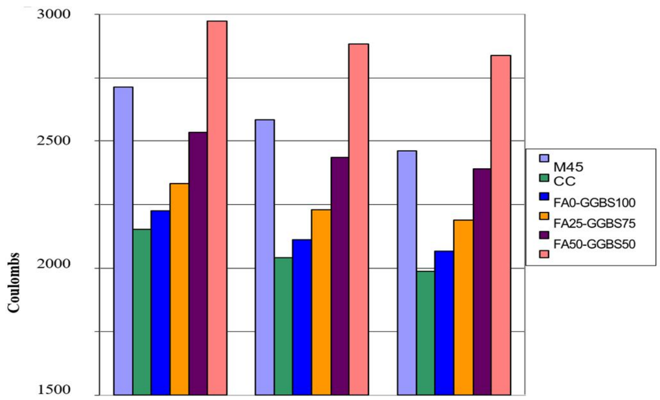

Figure 6: RCPT of mixes

Figure 6 is a bar chart that shows how the RCPT charge passage changed over time for geopolymer concrete with different amounts of FA and GGBS. This variation is caused in part by the concrete's considerable age. Figure 7 is a bar chart that shows how the RCPT charge passage changed over time for geopolymer concrete with different amounts of FA and GGBS. This variation results from the concrete's considerable age. Figure 7 provides another example, showcasing a bar chart that illustrates the RCPT charges in ordinary concrete as they alter with age. When the mix proportions are FA: GGBS: 0:100, FA: GGBS:25:75, FA: GGBS:50:50, and FA: GGBS:75:25, the RCPT in geopolymer concrete is lower. Regardless of how old the concrete is, this is true. The illustration clearly demonstrates this. The RCPT of geopolymer concrete has the lowest value when compared to regular concrete since it comprises the mix proportion FA: GGBS: 0: 100. Each of the previously mentioned four proportions contributes to this situation. No matter how old the concrete is, the RCPT charge passage for geopolymer concrete with a 100% FA: GGBS mix is greater than that for ordinary concrete, as the figure illustrates. Regardless of how old the concrete is, this is true.

G. Acid attack test

We measured the compressive strength of cube-shaped samples for all curing recipes included in IS 516. This exam covered all formulas. We cast and tested three 150-by-150-by-150-millimetre cubical samples for each age and combination. Cast and tested these specimens. All test specimens were room-temperature cured. GPC samples underwent ASTM C 597-02 ultrasonic pulse velocity testing [18]. Compression testing followed. We examined the concrete sample's exterior acid resistance using ASTM C 267-01. We weighed each concrete specimen after 28 days of ambient cure. Submerging the specimens in a 3% sulphuric acid (H_2SO_4) solution followed.

Table 9: Performance of GPC before acid attack

Property		Mix Type				
		GGBS:100 - FA:0	GGBS:7 5 - FA:25	GGBS:5 0 - FA:50	GGBS:2 5 - FA:75	GGBS:0 - FA:100
Weight (kg)	Initial	8.12	8.09	7.76	7.61	7.5
	After acid attack	8.01	7.96	7.52	7.32	7.08
Loss of Weight (%)		1.2	1.6	3.09	3.81	5.6
Compressive Strength (MPa)	Initial	60.23	58.12	46.32	15.55	12.11
	After acid attack	53.02	46.42	34.82	10.32	8.41
Loss of Compressive Strength (%)		11.97	20.13	24.83	33.63	43.99
UPV (m/s)	Initial	3569	3372	3324	2980	360
	After acid attack	3272	2986	2796	2372	220
Loss of pulse velocity (%)		8.32	11.43	15.88	20.4	38.88

As shown in Table 9, the mix of GGBS:0 and FA:100 has higher values for weight loss, compressive strength, and pulse velocity than the other mixes. As the quantity of replaced GGBS increases, the percentage of reduction in weight, compressive strength, and pulse velocity values decreases. This is because the amount of GGBS that is replaced is increased. [15] The idea proposes that an increasing replacement level of GGBS is responsible for an increase in polymerisation, which in turn leads to the concrete being denser and refines the pore structure. This cycle persists until the concrete achieves complete refinement. Two of the variables that contribute to the material's resistance to the attack of sulphuric acid from the outside are its enhanced pore structure and its polymerisation.

H. Mechanical Properties of Fiber Reinforced GPC mixes

Table 10 presents the mechanical properties of various GPC mixes and conventional concrete. Fig.5.12 presents the pictorial variation of mechanical properties w.r.t mix and % of fibers.

Table 10: Mechanical property of GPC and conventional concrete mixes

Iechanical property	% of fibers	Mix type					
		Control	FA0-GGBS100	FA25-GGBS75	FA50-GGBS50	FA75-GGBS25	FA100-GGBS0
Compressive strength	0	51.39	60.23	58.12	46.32	15.55	12.11
	0.25	52.11	61.78	59.56	47.27	16.35	13.25
	0.5	53.67	63.82	61.14	48.54	17.42	14.67
	0.75	54.25	65.41	63.67	50.11	18.96	15.83
	1.0	55.42	66.23	64.86	51.43	19.85	16.54
Split tensile strength	0	3.44	3.56	3.23	2.06	1.36	1.16
	0.25	3.52	3.64	3.34	2.17	1.45	1.24
	0.5	3.69	3.82	3.46	2.26	1.56	1.33
	0.75	3.81	3.93	3.58	2.39	1.68	1.44
	1.0	3.96	4.12	3.68	2.47	1.76	1.51
Flexural strength	0	3.3	5.59	5.51	5.35	4.9	3.3
	0.25	3.42	5.71	5.63	5.44	5.02	3.41
	0.5	3.63	5.86	5.76	5.56	5.14	3.54
	0.75	3.84	5.98	5.88	5.71	5.29	3.69
	1.0	4.01	6.13	6.02	5.90	5.53	3.94

Table 10 shows compressive strength test results at 28 days curing for steel fibre volume fractions 0, 0.25, 0.5, 0.75, and 1.0. differences in strength between mixes with and without fibre. Table 10 that compressive strength increases with fibre content. For the combination FA0-GGBS100 (fly ash = 0%, and GGBS = 100%), the compressive strength without fibres is 60.23 MPa. With 0.25% fibre, its compressive strength is 61.78 MPa. The pressure is 63.82 MPa for 0.5% fibres, 65.41 MPa for 0.75%, and 66.23 for 1.0%. The link between the cement matrix and steel fibres, owing to microsilica, cement, and GGBS, better steel fiber-cement matrix interactions, and increased C-S-H formation increases compressive strength. Consistent internal integrity and fine fibre dispersion may boost compressive strength. However, steel fibres increase their compressive strength by sealing cracks. Table 10 shows split tensile strength at 28 days curing for steel fibre volume fractions 0, 0.25, 0.5, 0.75, and 1.0. strength fluctuations for many combinations with and without fibres. Table 10 that (i) the split tensile strength goes up with the percentage of fibres and (ii) the strength goes up with more fibre volume fractions. For instance, mix FA0-GGBS100 (with 0% fly ash and 100% GGBS) has split tensile strengths of 3.56 MPa for 0% steel fibre, 3.64 MPa for 0.25% steel fibre, 3.82 MPa for 0.5% steel fibre, and 4.12 MPa for 1.0% steel fibre. 1.0% steel fibre increases strength by 15% compared to the same mix without fibre. Other mixtures (Control, FA25-GGBS75, FA50-GGBS50, FA75-GGBS25, FA100-GGBS0) show similar findings. Steel fibres may prevent or arrest cracks by increasing their strength. Concrete fibres prevent interior microcracks.

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The increased fibre form, aspect ratio, distribution, and matrix-fibre bond are associated with increased mechanical qualities. 9 shows flexural tensile strength at 28 days curing for steel fibre volume fractions 0, 0.25, 0.5, 0.75, and 1.0. strength variations for many mixtures with and without fibres. Table 10 larger fibre volume fractions enhance flexural strength. The results for splitting tensile strength are similar. For example, mix FA0-GGBS100 (fly ash = 0% and GGBS = 100%) has flexural strengths of 5.59, 5.71, 5.86, 5.98, and 6.13 MPa for 0%, 0.25%, 0.5%, 0.75%, and 1.0% steel fibres. 1.0% steel fibre increases strength by 10% compared to the same mix without fibre. Other mixtures (Control, FA25-GGBS75, FA50-GGBS50, FA75-GGBS25, FA100-GGBS0) provide similar results. Looking more closely at Table 10 fibrous volume fractions improve flexural strength more than split tensile strength. Fibre alignment and orientation may explain it. The steel fibre form improves the fibre-matrix bond, increasing flexural strength. The steel fibres around the crack tips release fracture energy, increasing their strength. We recorded similar discussions about the mechanical characteristics of fibre-incorporated concrete mixtures.

I. Durability studies on Fiber reinforced GPC

Table 11 compares the RCPT values of various geopolymer concrete mixes. Figure 5.13 displays the RCPT values obtained for a variety of concrete mixes with and without fibres. Through the examination of Table 5.10 and Figure 5.13, it is possible to make the following observations: (i) For a concrete mix (a), the RCPT values are lower as the percentage of steel fibres increases. For instance, in the concrete mix FA0-GGBS100, the RCPT values are 1302, 1267, 1206, 1156, and 1095 for 0%, 0.25%, 0.5%, 1.755%, and 1.0% steel fibres, respectively. Fly ash is equal to 0%, while GGBS is equal to 100%. It is possible to notice a similar pattern with various types of concrete mixtures. The ASTM C1202 (2012) classification system has classified the RCPT as moderate/low based on its values.

Table 11: Durability various GPC and control mixes

Mix	% Fiber	Coulomb		Remark	Water absorption		% weight loss	% loss in compressive
		28 days	56 days		28 days	56 days		
FA0-GGBS100	0	1225	1302	Low	1.12	1.23	1.20	11.97
	0.25	1212	1267		1.02	1.14	1.13	10.83
	0.5	1119	1206		0.98	1.04	1.07	9.12
	0.75	1108	1156		0.82	0.95	1.01	8.73
	1.0	990	1095		0.71	0.85	0.85	8.34
FA25-GGBS75	0	1408	1448	Low	1.41	1.52	1.60	20.13
	0.25	1352	1386		1.32	1.47	1.52	18.32
	0.5	1302	1332		1.29	1.41	1.41	16.45
	0.75	1247	1267		1.18	1.34	1.28	15.76
	1.0	1121	1221		1.02	1.26	1.17	15.43
FA50-GGBS50	0	1628	1665	Low	1.98	2.03	3.09	24.83
	0.25	1592	1603		1.86	1.94	2.95	22.21
	0.5	1527	1554		1.77	1.86	2.87	20.43
	0.75	1458	1492		1.69	1.73	2.74	19.56
	1.0	1387	1425		1.54	1.63	2.61	18.65
FA75-GGBS25	0	2015	2069	Moderate	2.8	2.9	3.81	33.63
	0.25	1998	2011		2.78	2.83	3.76	31.24
	0.5	1922	1965	Low	2.69	2.74	3.64	29.86
	0.75	1865	1894		2.55	2.62	3.58	28.32
	1.0	1793	1832		2.47	2.5	3.32	26.87
FA100-GGBS0	0	2907	2946	Moderate	3.52	3.72	5.60	43.99
	0.25	2845	2883		3.48	3.61	5.21	40.34
	0.5	2784	2832		3.35	3.5	4.92	38.25
	0.75	2736	2775		3.28	3.39	4.73	37.11
	1.0	2654	2742		3.12	3.28	4.64	36.01

Control mix	0	2324	2424	Moderate	3.02	3.13	-	-
	0.25	2262	2354		2.98	3.02	-	-
	0.5	2225	2312		2.72	2.93	-	-
	0.75	2189	2265		2.69	2.81	-	-
	1.0	2112	2213		2.61	2.75	-	-

Table 11 displays the percentage of water absorption for both regular concrete and various geopolymer concrete mixtures. Table 11 displays the percentage of water absorption values for both regular concrete and various geopolymer concrete mixtures. Table 11 shows that, for a certain concrete mix (a), water absorption values decrease as the percentage of steel fibres increases. For instance, the percentage water absorption values for the concrete mix FA0-GGBS100 (fly ash = 0%; GGBS = 100%) with 0%, 0.25%, 0.5%, 0.75%, and 1.0% steel fibre are 1.23, 1.14, 1.04, 0.95, and 0.85, respectively. Different concrete mixtures exhibit a similar pattern. The randomly distributed fibres, which attempt to patch the majority of the microcracks and minimise continuous voids, might be responsible for the decrease in water absorption. [16,17] As a result As a result, GPC reinforced with fibres has a denser microstructure than GPC without fibres. Percentages To see how much weight and compressive strength different geopolymer concrete mixtures have lost, look at Table 11. It shows the numbers in a table format. that (i) for a certain concrete mix, (a) the percentage of weight loss and the percentage of compressive strength loss decrease as the percentage of steel fibres increases. For instance, the weight-loss percentages for the concrete mix FA0-GGBS100 (fly ash = 0%, GGBS = 100%) are 1.2, 1.13, 1.07, 1.01, and 0.85 for steel fibres, which are 0%, 0.25%, 0.5%, 0.75%, and 1.0%, respectively. For 0%, 0.25%, 0.5%, 0.75%, and 1.0% steel fibres, the percentage decrease in compressive strength because of a sulphate attack is 11.97, 10.83, 9.12, 8.73, and 8.34, respectively. Different concrete mixtures exhibit a similar pattern. The GPC specimens that were exposed to H_2SO_4 had very little calcium in the fly ash that was used. This meant that less calcium sulphate was formed, which made the specimens stronger against H_2SO_4.

IV. CONCLUSIONS

In geopolymer concrete, the compressive and split tensile strengths decrease as the FA content increases. This deterioration is dependent on the length of time that the concrete is allowed to cure. With increasing age, both the split tensile strength and the compressive strength of the material rise for a certain mix %. The mix proportions of FA: GGBS: 0:100 enable the geopolymer concrete to achieve the greatest compressive and split tensile strengths, regardless of the length of time it takes for the concrete to cure. After a period of seven days of curing, the compressive and split tensile strengths of geopolymer concrete begin to increase at a rapid pace; however, this rate begins to decrease as the concrete approaches maturity. A significant difference may be seen in the binding strength of geopolymer concrete when compared to that of conventional concrete that is constructed utilising conventional components. The bond strength of the geopolymer concrete accounts for about one-third of the compressive strength of the material. If the quantity of FA in the mix is increased, the binding strength of geopolymer concrete will decrease regardless of the amount of time it takes for the concrete to cure. When geopolymer concrete is allowed to mature, the binding strength of the material increases. The percentage of water absorption goes down when more GGBS is added to the geopolymer concrete mix, but this decrease depends on how long the concrete is left to cure. does not matter how much GGBS is included in the mixture; the proportion of water that is absorbed continues to decrease as the curing period in increases. According to the RCPT, preparing a geopolymer concrete mixture with a ratio of FA: GGGBS:0:100 leads to the production of thick concrete with a less porous structure. GPC (FA39-GGBS61) has a beginning material cost that is about 32 percent more than that of CC (M45) when the compressive strength measurement is taken after 28 days.

A few different geopolymer concrete mixtures were subjected to research, in which the impact of steel fibres was investigated. number of different percentages of fibres were added to the mixture, including 0.25%, 0.5%, 0.75%, and 1.0% by volume of construction material. e compressive strength, split tensile strength, and flexural strength of several different mixtures that included fibres were examined after 28 days. The study also examined the flexural strength as a mechanical parameter. In a similar manner, researchers investigated the durability characteristics of the comparable mixtures, such as RCPT, water absorption, and acid attack. The primary observation from the examinations was that the mechanical and durability properties of the mixtures were comparable. As As the amount of steel fibres added to fibre forced geopolymer concrete mixes increased, the mixes' properties got better.

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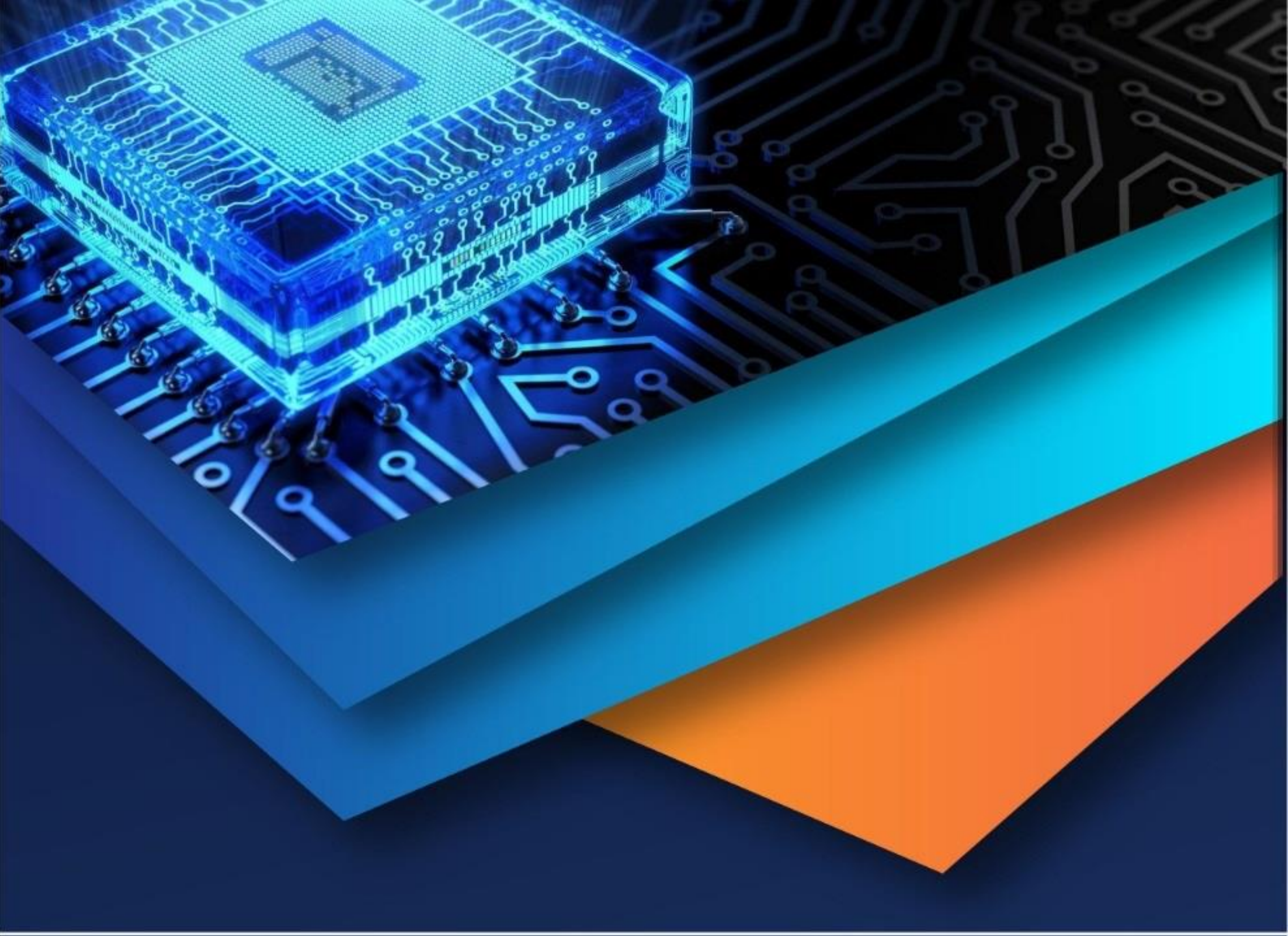

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