Effect of glass fiber and recycled aggregates on Geopolymer concrete

Shalika Mehta¹, Mohit Bhandari²

¹ Ph.D. Scholar, Chandigarh University Gharuan, Mohali (Pb), India
² Assistant Professor, Chandigarh University Gharuan, Mohali (Pb), India

Abstract: This study presents the effect of glass fiber and recycled aggregates on the strength properties of Geopolymer Concrete (GPC). The recycled aggregates were incorporated as a partial substitute for the natural coarse aggregates in the geopolymer concrete at 50%, 80%, and 100% by weight, and the results were compared to natural coarse aggregate. Class F fly ash is utilized as the source material for the production of Geopolymer and brought in from local sources. The effect of glass fiber (alkali resistant) with a length of 36 mm is also studied for the content ranging from 0.3, 1, 2, 3, and 3.5% based on the weight of the concrete. The flexural strength and compressive strength were compared at 7 days and 28 days for different cases. The results show that 1%, 1.5%, 2%, and 2.5% of glass fiber have exceeded the flexural strength of the geopolymer concrete by 20%.

Keywords: Geopolymer concrete; alkali resistance glass fiber; recycled aggregates; compressive strength; fly ash.

1. Introduction

With the expansion of infrastructure across the world any country's growth is dependent on its infrastructure, and concrete is widely used globally for the construction of new infrastructure. This eventually increases the demand for cement. Cement manufacturing in India has increased in recent years. According to these estimates, India is the world's second-largest cement manufacturer. On the other hand, Palomo reported, the annual global utilization of concrete is figured out that in 2050, it is expected to reach over 18 billion tonnes. Cement manufacturing operations emit a considerable amount of CO2, which has an effect on global warming [1–3].

McCaffrey predicted that ordinary portland cement production is increasing at a rate of around 3% each year, and this significantly affects global warming. In the last few years, researchers have been making an attempt to develop sustainable and environmentally-friendly solutions for producing a spacious amount of concrete for the global construction industry. Many materials and approaches have been investigated in order to discover a viable replacement for portland cement that can be used as a partial or total replacement [4–6]. Davidovits proposed that waste material containing aluminium (Al) and silicon (Si), like husk ash and fly ash, along with an alkaline will demonstrate a new binder. The binders were then named geopolymers by him. Which
we can say is concrete without cement. Because geopolymer concrete has good strength, their setting timeframes can be managed, and they stay magnificent for a greater period of time without needing to be repaired, they are suitable for construction and repairing infrastructures, as well as precasting units. Geopolymer concrete has a lot of features, including early strength, moderate consolidation, stability to freeze-thaw, sulphate resistance, and resistance to corrosion. The geopolymer binder is a cementious substance.
with low carbon dioxide. These high alkaline binders do not generate a combined alkaline reaction. They do not rely on limestone calcination to release CO₂. This technique has the potential to reduce CO₂ emissions from cement and aggregate companies by up to 80% [7–9]. In addition, fibre adhesion as a replacement for traditional steel reinforcement has been a key breakthrough in the building industry over the years. Because steel reinforcement is becoming more expensive, artificial and natural fibres are being investigated that can be used in concrete reinforcing. Fibres can slow the progression of cracks in shrinkage in concrete mixes and improve the post-crack strength of the material. Concrete's workability is reduced while using fibers, but its density, compressive, tensile, and flexural strengths are improved. Furthermore, with significant construction progress around the world, some of the preliminary concrete structures need to be repaired, rebuilt or demolished due to major damage. Recycled concrete is a type of recycled aggregate created by crushing leftover concrete, which can then be partially or totally replaced with natural aggregates to create new concrete, and it is an efficient method of converting waste concrete [10–12].

Seventy-five to eighty percent of concrete is made up of aggregates, thus using recycled materials has a great deal of potential. Natural aggregate can be replaced with recycled aggregate to reduce the amount of natural aggregate needed. However, because of the presence of a considerable variety of influential porous mortars on their surfaces and microcracks, recycled aggregates have a low visible density, absorption of high water, unbalanced gradation, poor crush resistance, low impact strength, and low durability. In addition [13–15], RCA is frequently combined with organic and inorganic materials. The presence of recycled aggregates has a negative impact on the workability, characteristics, of recycled concrete, limiting its widespread use in concrete production.

However, more research based on the impact of glass fibres on geopolymer concrete with reused aggregates is needed [16–18]. Hence, we require an alternative material to cement concrete. The recent research and development in the materials has made Geopolymer concrete a substitute for cement concrete which does not require any cement as shown in Figure 1.

![Figure 1 Process of production of geopolymer concrete](image)

With reference to the review of past research studies, the present studies focus on the effect of the recycled aggregates on the compressive and flexural strength of the geopolymer concrete at 50%, 80%, and 100% replacements. In addition, it, the effect of the glass fiber is also studied in a combination of with replacement percentages of recycled aggregates.
2. Methodology

This study compares the effect of (alkali resistance) glass fiber on Geopolymer concrete made from fly ash with recycled particles to standard geopolymer concrete with natural aggregates, adopting the Compressive Strength Test (ASTM-C39), Flexible strength (IS: 516-1959. As a binder in this experimental investigation into GPC, caustic soda and sodium silicate were chosen, the mass ratio of (Na2SiO3/NaOH) has an influence on GPC's performance and mechanical characteristics. According to the available research, a range between 1.3 and 2.8 is suitable for practical use. However, to maintain the GPC's economy, a medium value of 1.5 was chosen for this study, along with extra water and plasticizer. And the other important issue is to achieve the optimum result while making GPC is choosing an adequate ratio between 0.3 to 0.6 for the trial use of (AAL) to (FA). The goal of this study is to determine the best AAL- to-FA ratio for achieving optimum compressive strength. And also, in this research, 50,80 and 100 percent recycled aggregates have been investigated to find the suitable percentage of NCA replacement to reduce the cost, and also, the amount of waste is increasing globally.

2.1 Materials

2.1.1 Alkali resistance glass fiber: Glass fibers are formed of silicon oxide with a slight fraction of other oxides added. Glass fibers are typically spherical and straight, with diameters ranging from 0.005 to 0.015 mm. They may also be combined to form a bundle of glass fibers with a diameter of up to 1.3 mm. In this study, an alkali resistance glass fiber with enhanced zirconium oxide can resist alkalinity attack and is appropriate for use in concrete as shown in Figure 2.

Figure 2. Alkali resistance glass fiber

2.1.2 Fly ash: is a waste of melted charcoal combustion, collected by mechanical or electrostatic separators from thermal power plant flue gases. The raw material for the Geopolymer is Class F fly ash, which was acquired from a local area near the Mohali-Kharar flyover in India. Such kind of F.A complies with ASTM C 618. Table 1 shows the chemical composition of fly ash which is found out by XRF Analysis.

| Constituent | Na2O | MgO | Al2O3 | SiO2 | P2O5 | SO3 | K2O | CaO | MnO | Fe2O3 | L.O.I |
|-------------|------|-----|-------|------|------|-----|-----|-----|-----|-------|-------|
| % age content | 0.08 | 1.27 | 25.39 | 47.69 | 0.16 | 0.37 | 1.56 | 7.93 | 0.14 | 11.72 | 3.34  |
2.1.3. Alkaline materials:

Fly ash can be combined with an alkaline to function as a binder. In this paper, (NaOH) and (Na₂SiO₃) are being used as alkaline materials to produce an alkaline solution. Figure (2-3) illustrates Caustic soda pellets and sodium silicate liquid, while table (2) illustrates their chemical composition. The ratio of sodium hydroxide to that of sodium silicate is 1.5.

2.1.4 Recycled Coarse aggregates (RCA):

Recycled aggregates are constituted of crushed, graded inorganic particles collected from building and demolition waste. In the present paper, the recycled aggregates are sourced from the storage of waste materials at Chandigarh University concrete laboratory. The recycled aggregates were incorporated as a partial substitute for natural coarse aggregate in GC at 50, 80, and 100 percent by weight, and then compare to natural coarse aggregate at the same ratios. The disintegrated concrete was carefully crushed and irrigated, with 60 percent 10 mm, 20 mm, and 40%, with a maximum grain size of 40 mm. According to ASTM C 128, RCA has a specific gravity of 2.2 to 2.6, whereas NCA has a specific gravity of 2.7.

2.1.5 Fine aggregates:

In the present paper, the fine aggregate that was used during the experiment was clean river sand that flowed through a 4.75 mm sieve and remained on a 0.075 mm sieve having a specific gravity of 2.66 and a grading zone III following IS 383:1870. The properties of (N.A), RCA, and fine aggregates are mentioned in Table 2.

Table 2. Properties of aggregate

| Properties          | Natural coarse aggregates (N.A) | Fine Aggregates (F.A) | Recycled coarse aggregates (RCA) |
|---------------------|---------------------------------|-----------------------|----------------------------------|
| Bulk Density (Kg/m³) | 1522                            | 1650                  | 1250                             |
| Specific Gravity    | 2.7                             | 2.66                  | 2.5                              |
| Water Absorption (%)| 0.6                             | 0.9                   | 4.8                              |
| Fineness Modulus    | 7.08                            | 2.4                   | 7.47                             |

2.1.6 Superplasticizer:

They are known as water reducers, and they allow for a 30% reduction in water content. The need for water rises whenever fly ash is increased, leading to poor workability, which affects the target strength. To tackle this disadvantage, a superplasticizer is necessary to provide the appropriate degree of workability. As per previous literature, 1 to 3 liters per cubic meter of superplasticizer was proposed. Hence, in the present study, 2% superplasticizer by weight of fly ash has been used. The properties of the above superplasticizer are mentioned in below Table 3.
Table 3. Properties of Superplasticizer

| Properties      | Observed value         |
|-----------------|------------------------|
| Specific gravity| 1.15                   |
| PH              | 6.5-9                  |
| Appearance      | Brown free-flowing liquid |
| Chemical base   | Modified naphthalene formaldehyde |

2.2 Mix proportions

From the properties of the material as indicated in the above section, first of all, the preparation of alkaline activators is carried out. In the preparation of geopolymer the NaOH used is 80 kg/m³ at 14 M and Na₂SiO₃ is 120 kg/m³ at 14 M. Although alkaline solutions of 10, 12, 16, and 20 M have already been produced and used for fly ash activation in earlier research, we found 14 M to be much more effective. The solution was prepared using distilled water, and the weight ratio of alkaline liquid to fly ash is set at 0.5. The activator is created by combining a solution of Na₂SiO₃ and NaOH of 97 percent pure crystalline sodium hydroxide, and sodium silicate. Before 24 hours of utilization, the sodium hydroxide solution is prepared to regulate the rise in temperature due to its dissolution in the water. To make the alkaline liquid, sodium silicate (Na₂SiO₃) solution and Caustic soda (NaOH) are integrated. The glass fiber is added in various quantities ranging from 0.3 percent, 1%, 2%, 3%, and 3.5% by weight of concrete. After the chemicals were combined with the aggregate, the glass fiber was added to the mixture, like glass fibers are well known for their excellent strength, temperature resistance, alkali resistance, and corrosion resistance.

2.2.1 Mix Design with the variation of Sodium Hydroxide for GPC

Four mixed designs are adjusted to explore to optimize the empirical effect of the amount of caustic soda solution on the compressive strength of GPC as shown in Table 4.

Table 4 Details of Mix Design hybrid designs for various NaOH concentrations

| Sample ID | Fly ash | NaOH | Na₂SiO₃ | F. A | S. P | C.A | H₂O | Unit                  | NaOH (M) Concentration |
|-----------|---------|------|---------|------|------|-----|-----|-----------------------|------------------------|
| GPC M10   | 400     | 80   | 120     | 505  | 8    | 1178| 10  | Kg/m³                 | 10                     |
| GPC M12   | 400     | 80   | 120     | 505  | 8    | 1178| 10  | Kg/m³                 | 12                     |
| GPC M14   | 400     | 80   | 120     | 505  | 8    | 1178| 10  | Kg/m³                 | 14                     |
| GPC M16   | 400     | 80   | 120     | 505  | 8    | 1178| 10  | Kg/m³                 | 16                     |

2.2.2 Mix Design with the variation of alkali activator solution to fly ash weight ratio for GPC

To study the influence of the weight ratio parameter of alkaline activator liquid (AAL) along with fly ash (FA) on compressive strength, four mixed designs are prepared as shown in Table 5. To keep the test conditions constant, the ratio of Na₂SiO₃ solution to NaOH in all designs was 1.5 and the concentration of caustic soda or NaOH solution was 14 Mole. The mixed designs of this section are presented in Table 5.
Table 5. Details of mix designs with the variation of AAL/FA ratio

| Sample ID | Fly ash | NaOH | Na2SiO3 | F.A | C.A | S.P | Unit | Add. H2O | AAL/FA |
|-----------|---------|------|---------|-----|-----|-----|------|----------|--------|
| GPC40     | 400     | 80   | 120     | 505 | 1178| 8   | Kg/m³ | 10       | 0.4    |
| GPC45     | 400     | 80   | 120     | 505 | 1178| 8   | Kg/m³ | 10       | 0.45   |
| GPC50     | 400     | 80   | 120     | 505 | 1178| 8   | Kg/m³ | 10       | 0.5    |
| GPC55     | 400     | 80   | 120     | 505 | 1178| 8   | Kg/m³ | 10       | 0.55   |

2.2.3. Mix Design with the variation of Recycled Aggregate for GPC

In the present study, the recycled aggregates were utilized as a component substitute for natural aggregates in the production of GC at 50%, 80%, and 100% by weight and then compared to results with the use of natural coarse aggregate. The mixed design of this step is presented in Table 6

Table 6 Mix Design for various proportions of RCA

| Sample ID | Fly ash | RCA | F.A | NCA | NaOH | Na2SiO3 | S.P | Add HOH | unit | RCA (%) |
|-----------|---------|-----|-----|-----|------|---------|-----|---------|------|---------|
| GPC(0)    | 400     | -   | 505 | 1178| 80   | 120     | 8   | 10      | Kg/m³ | 0       |
| GPC50     | 400     | 589 | 505 | 589 | 80   | 120     | 8   | 10      | Kg/m³ | 50      |
| GPC80     | 400     | 942 | 505 | 237 | 80   | 120     | 8   | 10      | Kg/m³ | 80      |
| GPC100    | 400     | 1178| 505 | -   | 80   | 120     | 8   | 10      | Kg/m³ | 100     |

2.2.4. Mix Design with the variation of Glass for GPC

Glass fibers were added in different amounts of 0.3, 1, 2, 3 and 3.5% based on the weight of the concrete. After mixing the chemicals and aggregates, glass fibers were added to the mixture. Five sets of mix designs are prepared using natural coarse aggregates. In all designs, the sodium silicate solution to Caustic soda ratio is 1.5, and the Caustic soda solution concentration is 14 M. The mixed designs of this section are presented in Table 7.

Table 7. Mix Design with the variation of the content of glass fiber.

| Sample ID | Fly ash | F.A | C.A | NaOH | Na2SiO3 | S.P | Add HOH | Unit | Glass fiber (%) |
|-----------|---------|-----|-----|------|---------|-----|---------|------|-----------------|
| GPC(0.3)  | 400     | 505 | 1178| 80   | 120     | 8   | 10      | Kg/m³ | 0.3             |
| GPC(1)    | 400     | 505 | 1178| 80   | 120     | 8   | 10      | Kg/m³ | 1               |
| GPC(2)    | 400     | 505 | 1178| 80   | 120     | 8   | 10      | Kg/m³ | 2               |
| GPC(3)    | 400     | 505 | 1178| 80   | 120     | 8   | 10      | Kg/m³ | 3               |
| GPC(3.5)  | 400     | 505 | 1178| 80   | 120     | 8   | 10      | Kg/m³ | 3.5             |
2.3 Preparation of samples

Firstly, alkaline activating solutions were prepared to make the samples. For this purpose, in the first step, a sodium hydroxide solution with a specific concentration is prepared. This solution is then mixed with sodium silicate and superplasticizer solutions. The solution is prepared 24 hours before usage. Following that, on the days of the experiment in the laboratory, naturally coarse and fine aggregates are integrated for around 4-5 minutes in a laboratory pan mixer. Then, fly ash is added in the prescribed amount and lasted for approximately 2 minutes. Then, after the dry mixture, alkaline solution and superplasticizer are mixed to the dry material and again mixed for another five minutes. The same procedure is done along with recycled aggregates with specified mix designs for comparison purposes. After completion of mixing, the slump and compaction factor tests were performed to distinguish the workability of fresh concrete mix, as per the BS EN 12350 guidelines. The 150 mm diameter concrete cubes were filled to compressive strength test following the BS EN 1230-6. In addition, the prisms with dimensions of 100 mm x 100 mm x 500 mm are cast for flexural strength testing following the BS EN 12390-5 protocol. The specimens were cast in three layers laid out horizontally. Each layer was carefully tamped and vibrated for 10 seconds before putting in the oven for thermic curing at a temperature of 90 °C for 24 hours. Geopolymer concrete samples were stored at normal room temperature after heat curing and checked for 7 and 28 days since being reported.

3 Discussion of Results

The trend in the results got for the specific Mix design proportions with considered properties of materials for geopolymer concrete used in the present study is presented in the below sections.

3.1 Effect of weight ratio of sodium silicate solution to sodium hydroxide on the compressive strength of GPC.

Figure 3 depicts the effects of the NaOH/Na2SiO3 weight ratio on the compressive strength of GPC. When the weight ratio of sodium silicate solution to caustic soda is equal to one, the compressive strength at 7 and 28 days is 42 MPa and 49 MPa, respectively. With an increase in the ratio to 1.5, the compressive strength at 7 days and 28 days increased significantly (35% & 40%) to 56.7 MPa and 68 MPa. Furthermore, by increasing this ratio to 3, the compressive strength decreased significantly to a value of 35 MPa and 38 MPa at 7 days & 28 days (28% & 30%), in comparison to 1.5. As a result of this study, 1.5 was measured as the optimum ratio for this experiment.

The role of the alkaline activating solution, especially sodium hydroxide, is to dissolve the silicon and aluminum in the aluminosilicate sources and to produce SiO4 and AlO4 to produce the geopolymer gel. Adding a silicate solution such as sodium silicate to the solution increases the amount of SiO4 and the quantity of geopolymerization reaction. Geopolymer concrete's compressive strength is increased. Adding a small portion of sodium silicate solution (less than the ideal ratio) decreases the compressive strength because of the lower silicon content in the solution and, consequently, the lower SiO4 content. But on the other hand, adding an excess amount (more than the optimal ratio) of sodium silicate also reduces the compressive strength because, in this case, excessive amounts of SiO4 are produced, while the amount of AlO4 in the composition is constant (or limited) so that the Al/Si from the optimal range, the compressive strength decreases.
3.2 Effect of alkali activator solution with fly ash weight ratio on GPC employing NCA.

Figure 4 shows the influence of the weight ratio of alkaline activating solution to fly ash (AAL/FA) on the compressive strength of geopolymer concrete. As the trend in results shows, this parameter has a considerable effect on the compressive strength of GPC. At a ratio of 0.4, the compressive strengths of 7 and 28 days were measured as 50 and 56 MPa. By increasing this ratio to 0.5, the compressive strength of 7 and 28 days increased by approximately 18% and 21%, and the maximum compressive strength of 7 and 28 days was obtained. On the other hand, increasing this ratio increases the amount of alkaline activating solution and consequently increases the quantity of geopolymerization and the creation of more geopolymer gel, which results in increased compressive strength of GPC. Consequently, when this ratio was increased to 0.55, the 7 and 28-day compressive strength dropped to around 14 and 17%, respectively. The reason for this can be related to the increase in the ratio of water to dry blending with an increase in this ratio beyond 0.5. According to the results, 0.5 was selected as the optimal ratio for this experiment.
3.3 Effect of recycled aggregates on the compressive strength of GPC.

The effect of recycled aggregate on the compressive strength of geopolymer concrete with replacement of 50%, 80%, and 100% by weight is presented in Table 8. The results show that GPC with 100% NCA (0% RCA) yielded an average compressive strength of 54 MPa at 7 days and 65 MPa at 28 days. With the replacement of 50% of the recycled aggregates, the average compressive strength for 28 days is found to be 35 MPa and 42 MPa, and by increasing the RCA content to 80% replacement, the strength results for 7 and 28 days is 32 MPa and 39 MPa respectively. Finally, if we use 100 percent recycled aggregates, the result shows that the average stress of 54 MPa and 65 MPa using 100% NCA decreased to 31 MPa and 37 MPa.

Table 8. Compressive strength of GPC with utilization of RCA

| Sample ID | Replacement of RCA % | Compressive strength at 7 days | Compressive strength at 28 days |
|-----------|-----------------------|-------------------------------|-------------------------------|
| GPC 0     | 0                     | 54 MPa                        | 65 MPa                        |
| GPC 50    | 50                    | 35 MPa                        | 42 MPa                        |
| GPC 80    | 80                    | 32 MPa                        | 39 MPa                        |
| GPC 100   | 100                   | 31 MPa                        | 37 MPa                        |

3.4 Effect of glass fiber along with RCA in geopolymer concrete

This section shows the trend in the results of compressive, and flexural strengths of geopolymer concrete prepared with three replacement ratios of recycled aggregates; 50%, 80%, and 100% with NCA. In addition to it, the glass fibers with five different proportions by weight of concrete are added as 0.3%, 1%, 2%, 3%, and 3.5% to find out the influence of glass fiber on the strength characteristics of GC. The results are presented in Table 9.

The compressive strength values with 50% replacement of NCA with RCA and using 0.3% glass fibers at 7 days and 28 days were found to be 49 MPa and 56 MPa. The maximum values of the compressive strength are found to be 56 MPa and 62 MPa at 7 days and 28 days for the mix combination of 3% glass with 50% replacement with RCA.

The flexural strength values with 50% replacement of NCA with RCA and using 0.3% glass fibers at 7 days and 28 days were found to be 9.2 MPa and 12.3 MPa. The maximum values of the compressive strength are found to be 10 MPa and 13 MPa at 7 days and 28 days for the mix combination of 3% glass with 50% replacement with RCA.

According to the results gained from the experiment, adding glass fiber as an admixture to geopolymer concrete based on fly ash using recycled aggregates, the optimum result for adding glass fiber was 3%, which shows a 16% increase in compressive strength and an 18% increase in tensile strength, and finally a 21% increase in flexure strength. As the admixture percentage increased to 3.5%, compressive and flexure strengths decreased gradually by 3%, 4%, & 8%.
Table 9. Effect of Glass fiber on FA-based GPC utilizing RCA.

| S.NO | Glass fiber (%) | RCA (%) | Compressive Strength (MPa) 7-28 Days | Flexure Strength (MPa) 7-28 Days |
|------|----------------|---------|--------------------------------------|----------------------------------|
| 1    | 0.3            | 50      | 49 - 56                              | 9.2 – 12.3                       |
| 2    | 0.3            | 80      | 37 – 46.02                           | 9.1 - 12                         |
| 3    | 0.3            | 100     | 35 - 37                              | 8 – 8.7                          |
| 4    | 1              | 50      | 52 - 58                              | 9.5 – 12.6                       |
| 5    | 1              | 80      | 37.2 - 45                            | 9 – 11.5                         |
| 6    | 1              | 100     | 32 – 35.7                            | 7.8 – 8.1                        |
| 7    | 2              | 50      | 55 - 59                              | 9.7 – 12.8                       |
| 8    | 2              | 80      | 39 – 46.2                            | 9.3 - 12                         |
| 9    | 2              | 100     | 35.7 - 41                            | 8.2 – 8.9                        |
| 10   | 3              | 50      | 56 - 62                              | 10 - 13                          |
| 11   | 3              | 80      | 42 - 49                              | 8.7 - 9.1                        |
| 12   | 3              | 100     | 37 - 43                              | 8.6 – 8.99                       |
| 13   | 3.5            | 50      | 50 - 55                              | 9 - 12                           |
| 14   | 3.5            | 80      | 40 - 45                              | 8.1 – 8.8                        |
| 15   | 3.5            | 100     | 33 - 37                              | 7.8 - 8                          |

4. Conclusion

An experimental study is conducted to evaluate the strength properties of geopolymer concrete with the addition of glass fiber varying from 0.3%, 1%, 2%, 3%, and 3.5% by weight of concrete and replacing the natural aggregates with recycled aggregates with replacing in different ratios like 50% 80%, and 100% with natural aggregates. In addition, some of the most effective properties that affect the compressive strength of geopolymer concrete have been investigated in the present study like the amount of sodium hydroxide solution and the ratio of alkali activator to fly ash. The compressive strength and flexural strength tests were carried out for different mix proportions to understand the effect of considered materials affecting the properties of geopolymer concrete. Based on the specific material properties and mix proportions considered in this study, the main conclusion inferred from the test results are appended below:

1. The glass fibers added in geopolymer concrete made some positive changes in the compressive, and flexure strengths of geopolymer concrete. Utilization of 3% glass fiber by weight of concrete gained the maximum strength among the other proportions which was seen 16% increasing at compressive strength, and 21% increasing in flexure strength.
2. Geopolymer concrete strength decreased as RCA % increased to 50% replacement the compressive strength decreased between 25 -33%. This issue can be solved by adding fiber.
and it is because of the loose mortar around the RCA which is not allowing the proper bonding between aggregates and alkali activator solution along with the fly ash.

3. The optimum weight ratio for sodium silicate along with caustic soda for making GPC was found to be 1.5, which gained the maximum compressive strength.

4. The weight ratio of alkaline activating solution to fly-ash plays a key role in gaining the maximum strength of concrete. Among the different ratios, 0.5 leads to the highest compressive strength.

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