STUDY ON PROPERTIES OF GEOPOLYMER CONCRETE USING HYBRID FIBRES

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ABSTRACT: Due to the ongoing loss of the ozone layer and the issue of global warming, the building industry has recently become increasingly cognizant of the importance of employing more environmentally friendly construction materials. Geopolymer concrete (GPC) has started to draw considerable interest from scholars, researchers, and construction practitioners because of its benefits in replacing cement with by-product waste and reducing greenhouse gas emissions during production. It also outperforms traditional concrete in terms of mechanical qualities and endurance. Despite its benefits, GPC is only used in a limited number of applications.

This paper describes the various proportions of fly ash (100%, 90%, 85%, 80%) and bagasse ash (10%, 15%, 20%) based geo-polymer concrete. For the making of concrete, fly ash having low-calcium (Class F) is substituted for Ordinary Portland cement (OPC) as the raw material. According to earlier research, adding bagasse ash to Geopolymer concrete reduces its strength by more than 10%. The effects of strength and durability parameters were studied using silica fume (5%) and hybrid fibres (1%), and the findings revealed that GPC has increased durability and strength with the addition of silica fume and hybrid fibres. This GPC has mechanical and durability properties equivalent to OPC concrete. GPC is not only good for the environment, but it also has outstanding mechanical properties. In the future, it might be a very useful material.

Key words: Fly-ash, Bagasse ash, Silica Fume, Hybrid Fibres.

1.Introduction

Concrete made using Geopolymer concrete instead of OPC is an alternative to that made with OPC as the binder. It's being developed as an environmentally friendly alternative to traditional cement-based concrete because it emits less CO₂. It has been discovered that various industrial by-products, such as fly-ash (FA), slag (GGBS), metakaolin, rice husk ash (RHA), palm oil fuel ash, etc., in conventional and GPC, may be used as partial and full cement replacements. Cement is one of the most widely used building materials, with an annual production of over 11 billion tonnes.

In this work, GPC was made by substituting extra cementitious materials like silica fume, fly-ash, and bagasse ash for cement, and also polypropylene fibres and steel fibres in varying proportions. The trial mixes were made, as well as a mix that included as the final mix design, good workability was used.

Cement-less alkali-activated concrete will be built, and the chemical modifications effects to alkaline activators will be studied on the compressive strength and microstructure of the mortar. Chemical modifications in alkaline activators had a substantial impact on early strength with increasing molarity, according to the findings. Furthermore, SEM and EDS analyses of the structure revealed that the Al and Si components had a significant impact on the mortar structure. The examination of porosity allowed us to indirectly validate the extraordinary mechanical performance achieved by polymerization activation based on the chemical components of alkaline activators. Gum Sung Ryu et al.[1]. Steel fibres (0.25 percent by volume), hybrid polypropylene (0.075 percent by
volume), and steel fibres (0.175% by volume) affected the mechanical and durability qualities of geopolymer concrete composites. The addition of hybrid fibres to GPC increased its mechanical characteristics and also demonstrated to reduce water absorption levels. D. Lakshmaiah et al.[2].

As compared to traditional concrete, geopolymer concrete showed mechanical qualities, lifespan, and structural aesthetics. According to the results, geopolymer concrete may be divided into six categories based on their alumina silicate content. Fly ash based, metakaolin based, slag based, rice husk ash based, high calcium wood ash based, and a mix of aluminosilicates. Chau-Khun et al. [3]. Mortar, concrete, and other building materials' short and long-term mechanical properties and durability were both improved by using SCBA in cementitious materials. Qing Xu et al. [4].

A comparison of GPC reinforced with several kinds of fibres (Polypropylene or PP, 2-part PP, 4-part polyolefin) and its mechanical and physical properties (0.15, 0.2, and 0.25 percent). There was no difference in resistance to higher temperatures when using fibres as opposed to non-fibers Amir et al, [5]. The characteristics and hardness of concrete may be affects by using 5%, 10%, or 15% SCBA (chloride migration, carbonation, and alkali-aggregate reaction). To reduce porosity and water absorption through capillarity, and increase the strength of concrete, the tested ash exhibited a strong pozzolanic activity. As a result of the reduced alkaline reserve, the carbonation rate and lifetime of the concrete containing SCBA were both reduced. Through decreasing chloride diffusion coefficients, SCBA gave a 97.3 percent boost to the system's overall lifespan. SCBA addition of up to 5% reduced the Alkali-Silica Reaction due to the pozzolanic reaction and extra C-S-H production. José da Silva Andrade Neto et al. [6].

The various methods used to recover NaOH from industrial waste for use in the making of alkali solution This alternate strategy results in lower GHG emissions and more environmentally friendly construction Parthiban et al.[7]. Compressive strength improve with addition of fibres of ternary blend geopolymer concrete (TGPC) in mono and hybrid form at varying volume fractions. TGPC2 has a strength of 1%, while TGPC5 has a strength of 17 percent. The rupture modulus, and elasticity modulus of TGPC all increase significantly as the fibre volume percentage is increased. The split tensile strength ranged from 18 percent to 39 percent. The modulus of rupture ranged from 7% to 39%, while the elasticity modulus was 5% to 32%. Mechanical properties of TGPC significantly improved when addition of fibers. V. Sathish Kumar[8].

The values for HFRC blends were marginally improved. However, hybrid fibre reinforced concrete showed improved results in tensile strength under uniaxial tension. When Polypropylene and Polyester fibres are combined to make hybrid fibre reinforced concrete, the resulting mix is stronger and more durable than either the mono counterpart or the control mix. It's effective to grade polyester and polypropylene fibres, and the best concrete mix is 75% polyester fibre and 25% polypropylene fibre Srikanth Koniki[9]. In comparison to its effect on compressive performance, nanosilica has no effect on flexural strength; nevertheless, when combined with hybrid fibres, mechanical qualities can be significantly improved. Keyu Chen [10].

Different fibre geometries, curing regimes, and activator concentrations of NaOH (10M and 12M) have been tested on the first peak strength, including ambient curing and heat curing at 60°C for 24 hours. A fibre deformation ratio was utilized to quantify the fibre shape on geopolymer composite performance. With macro fibre reinforcement and heat curing, the mechanical properties are dramatically increased. Heat curing also enhances the initial peak load of all fibre reinforced geopolymers composites, according to the findings. Amer Bhutta [11]. The inclusion of glass fibre or steel fibre to the concrete increased its uniaxial compressive response. In uniaxial compression tests using GSFRS, graded FRC outperformed mono FRC. GrG (75 percent short fiber+25 percent long fiber) grading of glass fibres outperformed all other MGFRC and GrGFRC mixes. Similarly, all other MSFRC and GrPFC combinations used GrSIII grading to improve performance S.R.R. Teja
Prathipati[12].

2. Materials and Methods

GPC preparation requires the mixing of various industrial by-products. In this study, the materials that have been incorporated into this study have been discussed in detail.

This paper required making of fly ash based GPC using fly ash, silica fume and bagasse ash, sodium silicate(Na$_2$SiO$_3$) and sodium hydroxide(NaOH) as alternative cementitious materials. Steel fibres (SF) and Polypropylene fibres (PP) in specified percentages along with the above-mentioned materials in varying proportions.

2.1. Fly Ash:

Burning pulverized coal in a power plant produces fly ash, a fine powder that is a byproduct. Phosphorous and siliceous materials are found in fly ash. Pozzolan is the chemical name for the compound. Class F and Class C fly ash are subdivided based on the kind of coal and the combustion procedure used to manufacture it. We utilised class F fly ash. Table 2.1(a)& (b) shows the fly ash's characteristics. Fly ash is seen in Figure 2.1.

2.2. Sugar cane bagasse ash(SCBA):

The sugar manufacturing process's last byproduct is SCBA. It is common to use bagasse as a cogeneration fuel to generate steam and electricity.

2.3. Silica Fume(SF):

Silica fume is a by product of the ferrosilicon industry, and also the manufacturing of silicon metal. Around 80 to 85 percent is made up of silica and alumina. The microstructure of concrete is improved by the silica. Due to its chemical and physical properties, extreme fineness, and high silica content, SF is a highly reactive pozzolan. As can be seen in Table 2.3, SF has the following characteristics. The SF is seen in Figure 2.3.

2.4. Steel Fibres:

Hooked-end ASTM A-820M 06 steel fibres are used. A 30 mm long piece of 0.5mm diameter steel wire with a straight cross-section. The properties of steel fibres shown in Table 2.4.Figure 2.4 represent the steel fibres. Steel fibres purchased from sanjay impex, Karnataka.

| Chemical Composition | Percentage(%) |
|----------------------|---------------|
| SiO$_2$              | 51.98         |
| Al$_2$O$_3$          | 23.04         |
| Fe$_2$O$_3$          | 5.04          |
| CaO                  | 4.5           |
| MgO                  | 0.9           |
| SO$_3$               | 0.1           |
| L.O.I                | 0.85          |

Table 2.1 (a) Chemical Properties

| Properties       | Values   |
|------------------|----------|
| Specific Gravity | 2.64     |
| Specific Surface area | 370 m2/kg |

Table 2.1 (b) Physical Properties

Figure 2.1 Fly Ash

Each tonne of burned bagasse can produce 30-45 kg of SCBA, which can result in a good quantity of SCBA. The characteristics of SCBA shown in Table 2.2. Figure 2.2 represent the SCBA.

Figure 2.2 SCBA

Figure 2.3 Silica Fume

Figure 2.4 Steel Fibres

Each tonne of burned bagasse can produce 30-45 kg of SCBA, which can result in a good quantity of SCBA. The characteristics of SCBA shown in Table 2.2. Figure 2.2 represent the SCBA.
Table 2.2 SCBA Chemical Composition

|          |       |
|----------|-------|
| SiO₂     | 66.12 |
| Al₂O₃    | 15    |
| Fe₂O₃    | 7.16  |
| CaO      | 2.57  |
| MgO      | 1.19  |
| SO₃      | 0.26  |
| Na₂O     | 0.54  |
| K₂O      | 3.52  |
| P₂O₅     | 1.14  |
| LOI      | 9     |
| SiO₂+Al₂O₃+Fe₂O₃ | 88.28 |

Table 2.3. Silica Fume Properties

|          |       |
|----------|-------|
| Specific Gravity | 2.2    |
| Mean Frain Size (µm) | 0.15  |
| Specific Area cm²/gm | 150000-300000 |
| Colour     | Light Dark Grey |

Table 2.4 Properties of steel fibers

|          |       |
|----------|-------|
| Specific Gravity | 7.85 |
| Diameter (mm)     | 0.5   |
| Length (mm)       | 30    |
| Aspect ratio (l/d) | 60   |
| Tensile Strength(MPa) | 1100 |
| Elastic Modulus(MPa) | 205  |

2.5. Polypropylene Fibres:
Polypropylene fibre, commonly known as polypropene or PP, is a synthetic fibre mainly composed of 85% propylene that is utilized in a wide range of applications. It's utilized in a variety of industries. Because of their flexibility and ability to conform to form, polypropylene fibres diminish the extent of plastic shrinkage cracks. Polypropylene fibres purchased from jogani reinforcement in amazon.
### Table 2.5. Properties of Polypropylene fibres

| Property                        | Value     |
|---------------------------------|-----------|
| Specific gravity                | 0.91      |
| Thermal conductivity            | Low       |
| Alkali Resistance               | Alkali Proof |
| Water Absorption                | Negligible|
| Melting point(°C)               | 164       |
| Acid and chemical resistance    | Very high |

#### Figure 2.5. Polypropylene Fibre

2.6. Fine Aggregate:
The fine aggregates conforming to Zone-II according to IS: 383-2016 is used. Specific gravity of river sand is 2.35 and water absorption 6.38%. Figure 2.6 shows the fine aggregate.

#### Figure 2.6. Fine Aggregate

2.7. Coarse Aggregate:
The crushed granite aggregate used in this study is IS 383-2016 20mm in size. In terms of specific gravity 2.78, coarse aggregate has a 1.6% water absorption. Figure 2.7 shows the coarse aggregate.

#### Figure 2.7. Coarse Aggregate

2.8. Alkaline Activators:
Alkaline activators such as NaOH and Na<sub>2</sub>SiO<sub>3</sub> are utilized in GPC. Mixing powdered aluminosilicate with an alkaline activator is the process of alkaline activation. It creates a paste that sets and hardens in a short amount of time. The most common alkaline reactor is sodium or potassium hydroxide. They're utilized in conjunction with a sodium or potassium silicate solution. Because NaOH and Na<sub>2</sub>SiO<sub>3</sub> have a higher geopolymerisation rate, they are more widely employed. Sodium silicate solution is being used to bind the solution and alkali hydroxide is used to dissolve it. Water is used to dissolve sodium hydroxide, resulting in a semi-solid paste. The pozzolanic process is enhanced by mixing sodium hydroxide/sodium silicate solution.

### 3. Mix Design of GPC:

| Component                                | Value     |
|------------------------------------------|-----------|
| Unit Weight of Geopolymer concrete       | =2400 kg/m³ |
| Percentage of Combined Aggregate         | =77%      |
| Mass of Total Aggregate                  | =1848 kg/m³ |
| % of 20mm coarse aggregate               | =63%      |
| Mass of 20mm Coarse Aggregate            | =1164.24 kg/m³ |
| % of 4.75mm sieve passing sand           | =37%      |
Mass of 4.75mm sieve passing sand = 0.37 x 1800 = 683.76 kg/m³
Mass of Cementitious Material and Alkaline Liquid = 2400 – 1848 = 552 kg/m³
Alkaline solution to Fly ash Ratio = 1:0.45
Sodium hydroxide to Sodium silicate ratio = 1:2.5
Mass of Cementitious material = 552/1+0.45 = 380.69 kg/m³
Mass of Alkaline solution = 552 - 380.69 = 171.31 kg/m³
Mass of Sodium hydroxide Solution = 171.31/1 = 2.5 = 48.94 kg/m³
Mass of sodium silicate Solution = 171.31 – 48.94 = 122.36 kg/m³
Sodium hydroxide molarity concentration = 8
Molecular weight of NaOH = 40 gm/mol
Quantity of NaOH = 8 x 40 = 320 gm/l
Quantity of water to be added for NaOH solution = 1000 ml
Total quantity of NaOH Solution = 1320 ml

3.1. Quantity of Materials per m³ of GPC Mix:

Cementitious Material (FA+SCBA+SF) = 380.69 kg/m³
Fine aggregate = 683.76 kg/m³
20mm size coarse aggregate = 1164.24 kg/m³
Mass of NaOH Solution = 48.94 kg/m³
Mass of Na₂SiO₃ Solution = 122.36 kg/m³
Liquid to Cementitious Material Ratio = 0.45

Table 3.1. Mix Proportions

| Mix | OPC kg/m³ | Fly Ash kg/m³ | Bagasse Ash kg/m³ | Silica fume kg/m³ | Steel Fibre kg/m³ | Polypropylene kg/m³ | NaOH kg/m³ | Na₂SiO₃ kg/m³ | Course Aggregate kg/m³ | Fine Aggregate kg/m³ |
|-----|-----------|---------------|--------------------|-------------------|------------------|---------------------|-------------|--------------|----------------------|----------------------|
| M0  | 380.69    | -             | -                  | -                 | -                | -                   | 48.94       | 122.36       | 1164.24              | 683.76               |
| M1  | -         | 380.69        | -                  | -                 | -                | -                   | 48.94       | 122.36       | 1164.24              | 683.76               |
| M2  | -         | 342.62        | 38.06              | -                 | -                | -                   | 48.94       | 122.36       | 1164.24              | 683.76               |
| M3  | -         | 323.58        | 57.10              | -                 | -                | -                   | 48.94       | 122.36       | 1164.24              | 683.76               |
| M4  | -         | 323.58        | 38.06              | 19.03             | -                | -                   | 48.94       | 122.36       | 1164.24              | 683.76               |
| M5  | -         | 323.58        | 38.06              | 19.03             | 23.99            | 23.99               | 48.94       | 122.36       | 1164.24              | 683.76               |
| M6  | -         | 304.55        | 76.13              | -                 | -                | -                   | 48.94       | 122.36       | 1164.24              | 683.76               |
| M7  | -         | 304.55        | 57.10              | 19.03             | -                | -                   | 48.94       | 122.36       | 1164.24              | 683.76               |
| M8  | -         | 304.55        | 57.10              | 19.03             | 23.99            | 23.99               | 48.94       | 122.36       | 1164.24              | 683.76               |

4. Results and Discussion:

4.1. Compressive strength
After 7 and 28 days of ambient curing, the compressive strength of a 150mm cube was evaluated. GPC compressive strength is shown in Table 4.1. M5 has the greatest compressive strength of GPC. Figure 4.1 illustrates the ideal compressive strength.
Table 4.1. Compressive Strength for 7 and 28 days

| Mix | Compressive Strength (MPa) |
|-----|----------------------------|
|     | 7 days                     | 28 days |
| M0  | 19.05                      | 29.01   |
| M1  | 20.07                      | 30.60   |
| M2  | 19.40                      | 29.77   |
| M3  | 19.00                      | 28.00   |
| M4  | 21.01                      | 28.50   |
| M5  | 21.50                      | 30.00   |
| M6  | 19.90                      | 27.50   |
| M7  | 20.01                      | 28.10   |
| M8  | 20.50                      | 28.48   |

Figure 4.1. Compressive Strength for 7 and 28 days

4.2. Split Tensile Strength
Conforming to ISO 516-2016, test periods are seven and 28 days for cylinder specimens (300mm height and 150mm diameter). Mix 5 has the highest split tensile strength when compared to the other mixes. The split tensile strength test results are shown in Table 4.2. The ideal split tensile strength is shown in Figure 4.2.

Table 4.2. Split Tensile Strength for 7 and 28 Days

| Mix | Split Tensile Strength (MPa) |
|-----|-----------------------------|
|     | 7 days                      | 28 days |
| M0  | 1.66                        | 2.50    |
| M1  | 1.74                        | 3.01    |
| M2  | 1.65                        | 2.71    |
| M3  | 1.52                        | 2.65    |
| M4  | 1.42                        | 2.59    |
| M5  | 1.61                        | 2.87    |
| M6  | 1.38                        | 2.03    |
| M7  | 1.45                        | 2.28    |
| M8  | 1.57                        | 2.35    |
Figure 4.2. Split Tensile Strength for 7 and 28 Days

4.3. Flexural Strength

Prism moulds (700x150x150mm) are tested for 7 and 28 days according to IS 516-2016. The table 4.4 shows the flexure strength of geopolymer concrete. In Figure 4.3, Mix5 depicts the optimum strength of GPC.

Table 4.3. Flexural Strength for 7 and 28 days

| Mix  | Flexural Strength (MPa) = 3Pa/bd² |
|------|----------------------------------|
|      | 7 days                           | 28 days  |
| M0   | 2.74                             | 4.94     |
| M1   | 3.06                             | 5.21     |
| M2   | 2.94                             | 5.01     |
| M3   | 3.27                             | 4.90     |
| M4   | 3.65                             | 4.82     |
| M5   | 2.88                             | 5.12     |
| M6   | 3.00                             | 4.38     |
| M7   | 3.50                             | 4.43     |
| M8   | 2.03                             | 4.81     |

Figure 4.3. Flexural Strength for 7 and 28 Days

4.4. Durability Test

Water Absorption Test.

After 28 days of ambient curing, concrete mix water absorption was evaluated on 150 mm cube specimens in according to the ASTM C642. The water absorption test results for concrete mixtures are
shown in Table 4.4 and in Figure 4.4. When compared to other mixes, M3 and M6 have the highest percentage water absorption.

### Table 4.4. Water Absorption Test Results

| Mix | Dry weight (Kg) | Wet weight (Kg) | Saturated water absorption(%) |
|-----|----------------|----------------|-----------------------------|
| M0  | 8.25           | 8.67           | 5.09                        |
| M1  | 8.19           | 8.50           | 3.79                        |
| M2  | 8.25           | 8.65           | 4.85                        |
| M3  | 8.23           | 8.78           | 6.68                        |
| M4  | 8.28           | 8.60           | 3.86                        |
| M5  | 8.33           | 8.62           | 3.48                        |
| M6  | 8.38           | 8.97           | 7.04                        |
| M7  | 8.40           | 8.69           | 3.45                        |
| M8  | 8.43           | 8.69           | 3.08                        |

![Figure 4.4. Water Absorption Test](image)

**Sulphate Attack Test.**

The acid test of concrete was tested using its weight loss and residual compressive strength. For this experiment, 150 mm concrete cubes were poured and kept at 27°C for 24 hours before being allowed to cure for 28 days. The specimens were removed after 28 days of curing and left to dry for one day. The initial cube weights were measured. In the process Sulphuric acid (H2SO4) dilute to 5% in water was used. Weighing the cubes before immersion in the corrosive water was an important step in the experiment. The weight loss of the cubes is assessed after immersion in the acid water.

### Table 4.5. Sulphate Attack Test Results

| Mix | Weight before immersion(Kg) | Weight after immersion(Kg) | weight loss(%) |
|-----|-----------------------------|----------------------------|---------------|
| M0  | 8.31                        | 7.92                       | 4.92          |
| M1  | 8.28                        | 8.00                       | 3.50          |
| M2  | 8.35                        | 7.99                       | 4.09          |
| M3  | 8.39                        | 8.05                       | 4.53          |
| M4  | 8.44                        | 8.13                       | 3.81          |
| M5  | 8.48                        | 8.18                       | 3.67          |
| M6  | 8.52                        | 8.24                       | 4.78          |
| M7  | 8.54                        | 8.27                       | 3.26          |
| M8  | 8.58                        | 8.32                       | 3.13          |
5. CONCLUSION

Sugar cane bagasse Ash and Silica fume, steel fibres and polypropylene are used in this work as a preliminary inquiry to see how they affect the mechanical and durability properties of fly ash-based GPC. Durability is tested after 28 days, whereas mechanical properties are tested after seven days and 28 days.

1. The compressive strength was shown to be similar in mix 5 (85% fly ash, 10% bagasse ash, 5% silica fume, 2% hybrid fibres), when compare to 100% OPC and 100% fly ash-based GPC.

2. The split tensile strength was shown to be similar in mix 5 (85% fly ash, 10% bagasse ash, 5% silica fume, 2% hybrid fibres), with addition of hybrid fibres when compare to 100% OPC and 100% fly ash-based GPC.

3. Flexural strength showed similar results in mix 5 with steel and polypropylene fibres comparing to the 100% OPC and 100% fly-ash based GPC.

4. The durability properties of this GPC that is water absorption and sulphate attack showed the better results. The water absorption is reduces when hybrid fibres are added, comes to the sulphate attack test increase the acid resistance of GPC with addition of hybrid fibres.

5. Since Geopolymer concrete is not only environmentally friendly but also has outstanding mechanical properties, conventional concrete can be replaced by geopolymer concrete.

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