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# Performance Evaluation of Self-cured Bio Geo-Polymer Concrete regarding Mechanical Strength and Durability

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***Abstract-*** The process of geo-polymerization widely occurs by heat or steam curing of geopolymer concrete (GPC) to improve its mechanical properties. Heat curing is the usual method for the development of its strength, which poses a challenge for in-field applications. This study emphasizes preparing fly ash based geopolymers under ambient settings without an external heat source. Using low calcium fly ash and 20% ordinary Portland cement (OPC) accelerates the curing of geopolymer concrete, eliminating the requirements for enhanced heat applications. During the experimental phase, samples were cured at room temperature (25 oC) and relative humidity of 65 ± 10%. Additionally, self-curing of geopolymers has been investigated in ambient curing conditions by utilizing bio additives including Terminalia chebula and natural sugar (honey). To achieve desired mechanical properties, such as compressive strength, optimized percentages of these bio additives have been determined. Moreover, durability properties of the GPC have been analyzed by conducting sorptivity test on the specimen. Both bio-additives were incorporated in different percentages by the weight of aluminosilicate minerals and prepared mixes of geopolymer concrete i.e. GPC1 and GPC2 respectively. Experimental results showed that GPC2 prepared by adding 1.5 % Terminalia chebula and 0% honey has improved the compressive strength by 3.10% as compared to controlled specimen (GPC0) cured at ambient conditions for 28 days. Durability analysis showed that with these percentages of Terminalia chebula and honey, the sorptivity coefficient (S) obtained for GPC2 is 1.88% less in comparison to controlled specimen GPC0, indicating the improved durability properties of prepared geopolymer concrete.

**Keywords:** Bio additives, Geo-polymerization, Geopolymer Concrete, Mechanical Properties, Sorptivity Coefficient

## 1. Introduction

The production of ordinary Portland cement, also known as OPC, uses a significant amount of thermal energy and accounts for 5-8 percent of global greenhouse gas emissions. An analysis of the emissions showed an alarming ratio of 1 - emissions of carbon dioxide and cement output. [1]. Based on a 5% annual growth rate, the forecasts indicated that global production would reach 4.38 billion tons by 2050[2]. For regular Portland cement concrete, there is an alternate low ecological footprint option called "Geo polymers."[3]. Waste aluminosilicate was used as the foundation material to create geopolymers[4]. Rich in silica (Si) and alumina (Al), minerals can be utilized as an initial source for polymerization reactions when they encounter alkaline solutions like hydroxides and silicates of alkalis.[5]

The procedure is generating polymeric chains of the three-dimensional.[6] It was discovered that the inclusion of calcium to a geopolymer material structure (OPC) improved its properties both when specimens were cured at room temperature and when they were cured at a temperature [7][2]A few research used room-temperature geopolymer concrete that had OPC added to it. Instead of using additional heat, geopolymer concrete dried quicker when less calcium-rich fly ash was used in place of part of the OPC in the entire binder [8]. The current study significantly focuses on the effects of partially substituting fly ash with OPC, a rate of 20% in a temperature-cured system of low-calcium fly ash-based geopolymer concrete [9]. Moreover, incorporation of bio additives in the GPC mixes is an important consideration for studying mechanical strength under ambient curing conditions.

## 2. Materials and the Methods:

The materials used in this study include: Fly ash (Class F, low calcium) from a thermal power station in Muzaffargarh, Punjab, Pakistan; Ordinary Portland Cement (OPC) from Best Way Cement Factory, added up to 20% as a source of calcium; aggregates (fine and coarse) from Margalla crush, tested in UET Taxila concrete laboratory; alkaline liquid (sodium silicate and sodium hydroxide flakes, 98% pure) mixed to create 8M NaOH solutions; superplasticizer (naphthalene sulphonate-based, available from local traders); and bio-additives (honey, and Terminalia chebula, purchased from local vendors and added in various proportions).

## 3. Methodology

### *3.1. Manufacturing Procedure of Geopolymer Concrete*

Details on the mix design for the geopolymer concrete were provided in Table 1. The geopolymer concrete mix design consisted of 80% fly ash and 20% OPC. The silicate ratio was adjusted to 2.5, and the alkaline liquid to aluminosilicate ratio was fixed at 0.45. Honey and Terminalia chebula were added as bio-additives, and additional water and superplasticizer. The mixes were cured at 25 ± 3°C and 65 ± 5% humidity after demolding at one day. In Table 2, **GPC0** is the control mix which includes the standard GPC components without any additives such as Terminalia Chebula or honey. **GPC1** contains the base GPC components along with 1.5% honey. **GPC2** incorporates 1.5% Terminalia Chebula into the base GPC components, without honey.

*Table 1: Ingredients for geopolymer concrete*

| Mix ID | Fly Ash: ($kg/m^3$) | Cement ($kg/m^3$) | Fine Aggregate ($kg/m^3$) | Coarse Aggregate ($kg/m^3$) | | | ($NaOH$) solution ($kg/m^3$) | ($Na_2SiO_3$) solution ($kg/m^3$) | Super-plasticizer ($kg/m^3$) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 20 mm | 12 mm | 6mm | | | |
| GPC | 320 | 80 | 546 | 382 | 528 | 364 | 51 | 129 | 7.9 |

*Table 2: Various proportions of Bio-additives used for the preparation of geopolymer concrete mixes.*

| MIX ID | Geopolymer (GPC) | Terminalia Chebula | Honey |
|---|---|---|---|
| GPC0 | Alkaline liquids, superplasticizer, fly ash and cement, fine and coarse aggregate. | 0% | 0% |
| GPC1 | | 0% | 1.5% |
| GPC2 | | 1.5% | 0% |

# 4. Results and Discussions:

## *4.1. Compressive Strength Test*

Three cubic samples of geopolymer concrete of size 150 mm X 150 mm X 150 mm were subjected to a compressive strength test in accordance with ASTM C109/C109M – 12 after a curing period of 28 days. The compressive strength outcomes of tests are displayed below in figure 1. The compressive strength values obtained for geopolymer concrete specimen is of the following order from maximum to minimum: GPC2>GPC0>GPC1

In GPC1 there is only a percentage of Honey. The compressive strength decreases by 3.10% as compared to controlled specimen GPC0. This is because honey is a humectant, and its presence has introduced excess moisture resulting in an increased water-to-geopolymer binder ratio, leading to a weaker concrete structure. Additionally, honey contains sugars that can react with the alkaline properties of the geopolymer binder, forming expansive compounds that cause internal stresses and reduce compressive strength. In **GPC2,** there is only percentage of Terminalia chebula (TC) resulting in increase in the compressive strength by 2.99% as compared to controlled specimen GPC0. The possible reasons include TC promotes the formation of calcium silicate hydrates (CSH), a key component of geopolymer concrete that contributes to its strength and durability.

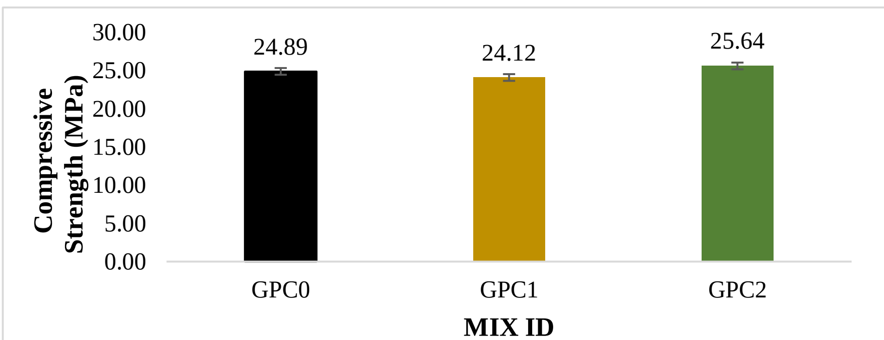


*Figure 1: Compressive strength of various mixes of GPC.*

## *4.2. Sorptivity test*

For the sorptivity test, three cylindrical specimen of 200 mm diameter and 100 mm height of geopolymer concrete have been casted and tested as per ASTM C 1585.The present research provides guidance about the geo polymer's ability to resist water penetration, which is crucial for assessing its durability. The outcomes obtained from the sorptivity test are presented below in figure 2. The sorptivity coefficient is a measure of the capacity of a porous material to absorb fluids, such as water. It is typically measured in units of mm/√min or cm/√sec. Here's the mathematical representation ((**1**) used for calculating the sorptivity coefficient:

$$\textbf{Sorptivity Coefficient }(\mathbf{S}) = \left(\frac{\boldsymbol{I}}{\sqrt{\boldsymbol{t}}}\right) \tag{1}$$

Where, **S** is the sorptivity coefficient in mm/√min or cm/√sec, *I* represent the cumulative absorption (mm or cm) and t is the time in minutes or seconds observed for evaluating the cumulative absorption values of specimen [7]. In **GPC1**, there is only 1.5% honey as a result the sorptivity coefficient increases by 6.42% as compared to controlled specimen GPC0. Honey is a humectant, which means it attracts and retains water. This increases the water content in the geopolymer concrete, leading to higher sorptivity. Similarly, **GPC2** contains only 1.5% Terminalia chebula (TC) in geopolymer concrete, the sorptivity coefficient decreases 1.88% as compared to controlled specimen GPC0.

Terminalia chebula (TC) contains corilagin which is known for their water-repelling properties, reducing water absorption and sorptivity.

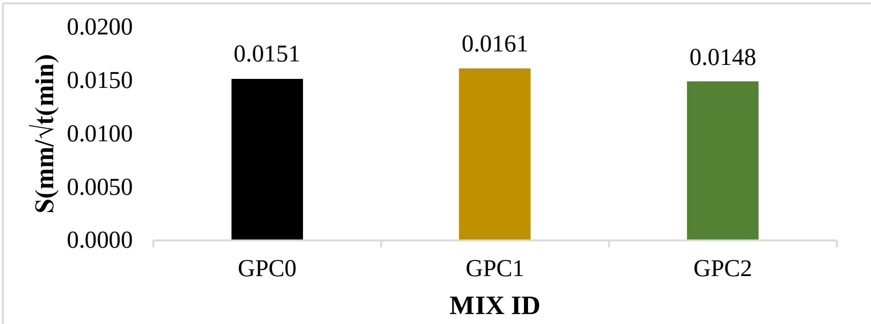


*Figure 2: Sorptivity coefficient of various mixes of GPC.*

## 5. Conclusion

Experimental results demonstrated that adding 1.5% Terminalia chebula to geopolymer concrete significantly improved its mechanical properties by enhancing the formation of calcium silicate hydrates, a key component of geopolymer concrete. This resulted in a 2.99% increase in compressive strength, indicating a notable improvement in the material's ability to withstand axial loads. Additionally, the inclusion of Terminalia chebula reduced the sorptivity coefficient by 1.88% due to its water-repelling properties. The increases and decreases in strength and durability obtained in the study are much smaller and fall within the limits of statistical errors. This study highlights the potential of Terminalia chebula as a natural additive for improving strength and durability, contributing significantly to the field of civil engineering.

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