An Investigation on Mechanical and Durable Properties of Eggshell Based Geopolymer Concrete using Flyash and GGBS

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Abstract

This research work represents an investigation of the mechanical, durable properties and microstructure of geopolymer concrete mixed using Eggshell powder, class F fly ash (FA) and Ground granulated blast-furnace slag (GGBS). An optimal combination of FA, GGBS and Eggshell powder was determined using the compressive strength tests of geopolymer pastes and to find the durable properties like acid attack test and sorptivity test were conducted with various different replacements of FA with GGBS and Eggshell powder. The test results are to be taken on the mix proportions of geopolymer concrete various mix to be taken at 28, 56, and 90 days respectively. This paper aims to examine the effects of chemical changes of reaction generating liquid on the strength and durable properties done to analyse the microstructure of the mortar through SEM, XRD, FT-IR and porosity assessments. The porosity analysis enabled us to indirectly verify the remarkable mechanical performance obtained by the activation of polymerization according to the chemical components of the Reaction Generating Liquid.

1. Introduction

Presently, construction and infrastructure industries are experiencing an agile growth curve owing to an outburst in the world population. Consequently, the demand for concrete as an essential construction material has also amplified significantly due to its exponential usage, which, in turn, increased the demand for the predominant binder in concrete—ordinary Portland cement (OPC). Unfortunately, the present OPC production process is highly energy intensive owing to the high temperatures required for the calcination of limestone. Further, deleterious gases like carbon dioxide, nitrogen oxide and SO₃ are emitted into the atmosphere, resulting in global warming and acid rain. For instance, the production of a ton of cement releases about one ton of CO₂ into the atmosphere and consumes almost 4GJ of energy. The cement industry alone contributes to approximately 7% of global CO₂ emissions. Consequently, this process is degrading the environment and increasing global warming through the emission of CO₂—a principal greenhouse gas. The production of OPC in 2014 amounted approximately to 390 million tons in India alone. Furthermore, India's cement demand is expected to reach 550 million tons per year by 2025. This is a serious threat to plants, animals and mankind across the planet. Intense research efforts are being devoted to the discovery of more eco-friendly coarse aggregate and fine aggregates [5]. The application of sustainable cementitious materials as a replacement for Portland cement in the construction industry will significantly contribute to the reduction of the environmental issues related to CO₂ emission and global warming. Geopolymer concrete (GPC) is a sustainable cement-less concrete, prepared with industrial by-product materials such as fly ash, slag and other waste materials. Although, past research studies show that GPC has excellent mechanical properties compared to OPC concrete durability performance is a key concern for its application in civil infrastructure. It has been reported that the carbonation resistance of GPC is lower than OPC concrete based on accelerated carbonation tests. Moreover, atmospheric-exposed GPC also validated the lower resistance to carbonation after several years of exposure. Considering chloride penetration, laboratory studies demonstrate that the fly ash-based geopolymer concrete exhibits lower chloride diffusion and less corrosion of the steel bar compared to OPC concrete. However, the chloride penetration of OPC concrete reduces with the age of the concrete (maturity factor) due to the continuous hydration reaction in OPC concrete with time after the casting of structures. It should be noted that the polymerization reaction in heat-cured fly ash-based geopolymer concrete is very rapid with little or no further reaction after a few days of curing. Therefore, the ingress of chloride ions in fly ash-based geopolymer concrete could potentially be higher than in OPC concrete after some years of exposure [8]. Recently, a great concern for many researchers has been the development of cementless concrete to reduce drastically the exhaustion of CO₂. The theoretical basis of polymerization as a major reaction mechanism of cementless concrete was established for the first time by the French researcher Davidovits in 1978, who used kaolinite (Al₂Si₂O₅(OH)) and alkaline activators. Thereafter, this topic was studied by numerous researchers, but active research was impeded due to problems related to production and economic efficiency. However, the recent rise of environmental degradation as a social issue has reactivated research on alkali-activated concrete using industrial by-products such as fly ash and blast furnace slag [1]. In terms of durability behaviour, several studies have been carried out to determine the durability performance of GPC in an accelerated laboratory
environment. The durability of concrete structures in the oceanic environment is affected by carbonation, chloride penetration and sulphate attacks. Ismail et al. \[12\] reported that the GPC has superior performance to chloride penetration, while Noushini et al. \[16\] and Patil et al. \[17\] confirmed the vulnerable effect in chloride media. According to some previous studies, GPC has a higher resistance to sulphate attack \[18, 19\]. Those studies have been conducted for short-term periods with accelerated testing methods and controlled laboratory environments. On the other hand, the lack of long-term durability studies in real exposed conditions is a significant barrier to the GPC application in the construction industry \[20\]. There are only a few studies have been conducted on the durability of a geopolymer in a really aggressive environment over the long-term period \[21–22\]. Therefore, to increase the GPC concrete application, prospective durability investigation in the real field environment needs to be studied \[2\].

2. Test Setup

2.1 Test plan

Fly ash, Eggshell powder, and GGBS were using Reaction generating solution samples using different mix proportions mixture of Table 1 show the details of the experimental plan and the ambient curing conditions. The reactivity was examined by mixing SiO₂/Na₂O = 0.6–1.5 using Flyash: GGBS: Eggshell powder (40:30:30), as shown in Table 6,7,8,9. Test specimens were prepared to determine the compressive strengths at curing ages of 28, 56, and 90 days in an ambient temperature as explained.

2.2 Behaviour of Materials:

The materials used for casting GP concrete specimens were aluminosilicate materials (class F FA, GGBS and Eggshell powder), aggregate, and Reaction generating liquid. Class F FA, obtained from the Manjung power plant at Perak in Malaysia, was used as the main binder material in the present experimental study. The average particle size of the FA is about 18 mm. The specific surface area of the FA is around 1.29 m²/g. GGBS was obtained from the steel plant at Penang in Malaysia. The average particle size of the GGBS is about 138 mm. The specific surface area of the GGBS is around 0.106 m²/g. The eggshell powder was obtained from the University of Tirupati. The average particle size of the eggshell powder is about 280 mm. The specific surface area of the eggshell powder is around 0.0536 m²/g. Figure 1 shows the particle size distributions of the FA, GGBS, and Eggshell powder. The chemical compositions of the FA, GGBS, and Eggshell powder are given in Table 1, which were determined by using X-ray fluorescence analysis.

<table>
<thead>
<tr>
<th>Chemical Name</th>
<th>Si(%)</th>
<th>Al(%)</th>
<th>Ca(%)</th>
<th>Mg(%)</th>
<th>O(%)</th>
<th>S(%)</th>
<th>Mn(%)</th>
<th>Fe (%)</th>
<th>K(%)</th>
<th>Sr(%)</th>
<th>Cu (%)</th>
<th>Zr(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flyash</td>
<td>31.59</td>
<td>22.35</td>
<td>0.28</td>
<td>15.42</td>
<td>56.51</td>
<td>0.047</td>
<td>0.007</td>
<td>0.804</td>
<td>0.319</td>
<td>0.004</td>
<td>0.006</td>
<td>0.011</td>
</tr>
<tr>
<td>GGBBS</td>
<td>23.11</td>
<td>17.50</td>
<td>27.57</td>
<td>0.725</td>
<td>–</td>
<td>0.96</td>
<td>0.39</td>
<td>0.518</td>
<td>0.603</td>
<td>0.039</td>
<td>0.002</td>
<td>0.023</td>
</tr>
<tr>
<td>Eggshell Powder</td>
<td>0.17</td>
<td>–</td>
<td>91.50</td>
<td>3.79</td>
<td>3.73</td>
<td>0.50</td>
<td>4.24</td>
<td>0.064</td>
<td>0.084</td>
<td>0.115</td>
<td>0.025</td>
<td>–</td>
</tr>
</tbody>
</table>

2.3 Nature of Materials
In this article, we clearly represent each material's behaviour with pH value ranges obtained. From that, we are going to explore the characteristics of the material to design the Geo-polymer concrete for the improvement of mechanical and durable properties with different mix proportion variations in the ambient curing temperature. In this experiment conduct, we are going to find the pH characteristics of each material like Flyash, GGBS, Eggshell powder and the liquid named Rgl also used as lubricant for the mixing for making Geo-polymer concrete. We have to note down the pH value ranges of each material by finding out the characteristics of it whether it may be alkaline/ acidic. By conducting the test on pH meter, we find that all the materials were under the alkaline nature with the values of 7 – 12. (pH – power of hydrogen)

### 2.4 Performance of Reaction Generating Liquid (RGL)

Geopolymers (GPs) can function as binders similar to Portland cement and are inorganic polymers consisting of the inorganic links shown in Fig. 2a. The above linkages become feasible due to the presence of alkali metal ions such as Sodium or Potassium for the purpose of Charge balancing in the Chain when 4-coordinated Silicon is substituted by 4-coordinated Aluminium Fig. 2b. These Alumino-silicate polymers are made from powdery Geopolymer Source Materials (GSMs), whose chemical oxide composition consists of $\text{Al}_2\text{O}_3$ and $\text{SiO}_2$, the most common examples being: Fly Ash (FA) and Ground Granulated Blast Furnace Slag (GGBS). For this powdery mix a liquid known as Reaction General Liquid. At present, one optimized RGL formulation is made available for the personnel working in the field of Geopolymer Technology, to generate polymerization reactions at ambient temperature conditions for the GSMs made from mainly several combinations of FA and GGBS for varieties of applications. During the preparation of RGL, a very careful relative proportioning of sodium hydroxide and silicate solutions becomes essential.

In the present case of factory-made RGL, it is Basically, such a mixture may contain, a few special chemical additives for obtaining improved Properties of geopolymer mix at fresh and hardened Stages.

### 2.5 Comparative studies on different liquids of Geo-polymer concrete

<table>
<thead>
<tr>
<th>Alkaline liquid</th>
<th>Reaction Generating Liquid</th>
</tr>
</thead>
<tbody>
<tr>
<td>It will take 24hrs prior to make the liquid</td>
<td>No need to make the liquid, instantly available</td>
</tr>
<tr>
<td>Expensive</td>
<td>Economy</td>
</tr>
<tr>
<td>Easily available</td>
<td>Order this material</td>
</tr>
<tr>
<td>Superplasticizer is required</td>
<td>No Superplasticizer is to be added</td>
</tr>
<tr>
<td>Water to be added</td>
<td>No need to add any water</td>
</tr>
<tr>
<td>Avg. Density − 1.35 kg/lit</td>
<td>Density - 1.20 +/- 0.05 kg/lit</td>
</tr>
</tbody>
</table>

---

Table 2

<table>
<thead>
<tr>
<th>Materials</th>
<th>pH value</th>
<th>Behaviour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flyash</td>
<td>7.85</td>
<td>Alkaline</td>
</tr>
<tr>
<td>GGBS</td>
<td>7.9</td>
<td>Alkaline</td>
</tr>
<tr>
<td>Eggshell powder</td>
<td>8.4</td>
<td>Alkaline</td>
</tr>
<tr>
<td>Reaction Generating Liquid (RGL)</td>
<td>12.19</td>
<td>Alkaline</td>
</tr>
</tbody>
</table>
XRD images of Flyash, GGBS and Eggshell powder

From the above Table 4 and Figs. 3a,3b and 3c the results on the peak values were showing that each and every mineral was formed in between 2θ to an intensity at various angles formed for the Flyash, Eggshell powder, and Bauxite powder. We observed that peak values of XRD results were showing on Flyash, Eggshell powder and Bauxite powder were showing in above Table 4.

SEM images of Flyash, GGBS and Eggshell powder

The presence of Flyash, Eggshell powder and Bauxite powder particles in the cracks is observed in SEM Figs. 3a,3b and 3c. The particle sizes of all the materials are similar to results in enhancing the properties. Eggshell powder particles are partially reacted and some fully reacted particles are seen frequently. A porous, heterogeneous mixture of non- or partly reacted grains, residual alkaline precipitates, and gel are observed. Crack growing at the area of accumulation of particles are clearly visible and Denser than all other concrete observed on the surface in Fig. 3c. Fly ash particles form weak links in the matrix resulting in crack propagation. Growth of cracks is randomly observed in the normal grade of concrete. The splitting of particles from the surface of the concrete is also observed. The light density of geopolymer concrete is observed in the same scale of magnification is observed in Fig. 3a. The present study brings in the following observations. In order to apprehend the polymerization of geopolymer which is based on GGBFS and fly ash, a comprehensive physical-chemical characterization has been followed through Fig. 3b. Further, XRD results bring in the reaction products of polymerization and hydration reactions. In the process of polymerization, NASH and CSH formation are observed. Also, the crystallinity range of the two products is noted in two different humps. It is also observed that XRD analysis is supported by EDX-XRF From Table 1 analysis of all the materials was explained visibly, thus demonstrating the existence of RGL in geopolymer concrete. Further, SEM analysis exhibits the being of low-density, gel-kind, needle-shaped materials that may further help as binder elements.

Table 5: FTIR Test Results
Wave number (cm\(^{-1}\)) & Transmittance (%) & Bond & Functional Group \\
--- & --- & --- & \\
Flyash & 1083.08 & 96.0 & C-H stretch & Aliphatic amines \\
 & 786.30 & 97.0 & C-Cl stretch & Alkyl halides \\
 & 951.65 & 97.0 & =C-H bend & Alkenes \\
 & 556.34 & 98.0 & C-Cl stretch & Alkyl halides \\
 & 2978.14 & 99.0 & C-H stretch & Alkanes \\
Eggshell powder & 1416.56 & 90.0 & C=C stretch & Aromatic \\
 & 874.29 & 95.0 & C-H "oop" & Aromatics \\
 & 710.11 & 98.0 & C-H "oop" & Aromatics \\
 & 2977.16 & 99.0 & C-H stretch & Alkanes \\
GGBS & 671.16 & 98 & C-Br stretch & Alkyl halides \\
 & 950.53 & 94 & O-H bend & Carboxylic acids \\
 & 1463.08 & 99 & C-H bend & Alkanes \\
 & 2979.07 & 99 & C-H Stretch & Alkanes \\

We plot the FTIR pictures of Flyash, Eggshell powder, and Bauxite powder and explain the wavenumber (cm\(^{-1}\)) to transmittance (%) to generate the link to the functional group from the aforementioned Table 5 and Figs. 4a, 4b, and 4c. Figure 2 displays the FTIR spectrum alterations brought about by the physical and chemical processes outlined previously. The spectra of each material were displayed at various wavelengths to construct the bond and functional group for various materials. In the Flyash, FTIR Spectroscopy of broad absorption bands was created to C-H stretch to the functional group of Alkanes and C-H stretch to the functional group of Alkanes at about ranges from 2978.14 cm\(^{-1}\) to 1083.08 cm\(^{-1}\). The several varied FTIR Spectroscopy absorption ranges. While for the bauxite powder, we found that the FTIR absorption rate was related to the different ranges of wavelengths that were seen as 539.65 cm\(^{-1}\) are C-Br stretch of functional groups named Alkyl halides and for another wavelength of 734.99 cm\(^{-1}\) are C-Cl stretch bond of formation to the functional group was Alkyl halides. The other ranges of wavelengths that this mineral absorbed were 1540.72 cm\(^{-1}\), 1745.32 cm\(^{-1}\), and 2933.23 cm\(^{-1}\). These wavelengths were bonded to the N-O asymmetric stretch of Nitro compounds, the C=O stretch of esters, the saturated aliphatic, and the C-H stretch of alkanes, which resulted in the formation of these compounds. FTIR Spectroscopy ranges for the eggshell powder's absorption rate of wavelength (cm\(^{-1}\)) to transmittance (%) were 710.11 cm\(^{-1}\) and 874.29 cm\(^{-1}\), respectively, producing the C-H "oop" bond to the functional group of Aromatics. The other large spectral absorption rate ranges were generated at 1416.56 cm\(^{-1}\), 2977.16 cm\(^{-1}\), and C-H stretch at alkanes and the creation of the functional group known as aromatic, respectively.

3. Test Results

Table 6: Mechanical properties
### Table 7: Durability properties using H$_2$SO$_4$ Solution

<table>
<thead>
<tr>
<th>$\text{SiO}_2$/Na$_2$O</th>
<th>Fine Agg (Kg)</th>
<th>Coarse Agg (Kg)</th>
<th>R.G.L (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20mm</td>
<td>10mm</td>
<td></td>
</tr>
<tr>
<td>0.6</td>
<td>337.6</td>
<td>331.7</td>
<td>221.1</td>
</tr>
<tr>
<td>0.8</td>
<td>338.9</td>
<td>332.9</td>
<td>221.9</td>
</tr>
<tr>
<td>1.1</td>
<td>326.5</td>
<td>320.8</td>
<td>213.8</td>
</tr>
<tr>
<td>1.3</td>
<td>329.5</td>
<td>323.7</td>
<td>215.8</td>
</tr>
<tr>
<td>1.5</td>
<td>318.3</td>
<td>312.7</td>
<td>208.5</td>
</tr>
</tbody>
</table>

### Table 8: Durability properties using HCL Solution

<table>
<thead>
<tr>
<th>$\text{SiO}_2$/Na$_2$O</th>
<th>Fine Agg (Kg)</th>
<th>Coarse Agg (Kg)</th>
<th>R.G.L (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20mm</td>
<td>10mm</td>
<td></td>
</tr>
<tr>
<td>0.6</td>
<td>337.6</td>
<td>331.7</td>
<td>221.1</td>
</tr>
<tr>
<td>0.8</td>
<td>338.9</td>
<td>332.9</td>
<td>221.9</td>
</tr>
<tr>
<td>1.1</td>
<td>326.5</td>
<td>320.8</td>
<td>213.8</td>
</tr>
<tr>
<td>1.3</td>
<td>329.5</td>
<td>323.7</td>
<td>215.8</td>
</tr>
<tr>
<td>1.5</td>
<td>318.3</td>
<td>312.7</td>
<td>208.5</td>
</tr>
</tbody>
</table>

### Table 9: Sorptivity ratio of Geo-polymer concrete
<table>
<thead>
<tr>
<th>Time (min.)</th>
<th>W.t in (Kg)</th>
<th>Gaining in wt.kg</th>
<th>C.M.F weight in kg</th>
<th>water (Vol. in mm$^3$)</th>
<th>Area (mm$^2$)</th>
<th>i (mm)</th>
<th>Time (√min)</th>
<th>Sorptivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>8.411</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>22500</td>
<td>0.000</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>8.413</td>
<td>0.002</td>
<td>0.002</td>
<td>2000</td>
<td>22500</td>
<td>0.0889</td>
<td>1.00</td>
<td>0.0889</td>
</tr>
<tr>
<td>2</td>
<td>8.415</td>
<td>0.002</td>
<td>0.004</td>
<td>4000</td>
<td>22500</td>
<td>0.1778</td>
<td>1.41</td>
<td>0.126</td>
</tr>
<tr>
<td>3</td>
<td>8.417</td>
<td>0.002</td>
<td>0.006</td>
<td>6000</td>
<td>22500</td>
<td>0.2667</td>
<td>1.73</td>
<td>0.154</td>
</tr>
<tr>
<td>4</td>
<td>8.418</td>
<td>0.001</td>
<td>0.007</td>
<td>7000</td>
<td>22500</td>
<td>0.311</td>
<td>2.00</td>
<td>0.155</td>
</tr>
<tr>
<td>5</td>
<td>8.419</td>
<td>0.001</td>
<td>0.008</td>
<td>8000</td>
<td>22500</td>
<td>0.3556</td>
<td>2.24</td>
<td>0.158</td>
</tr>
<tr>
<td>9</td>
<td>8.422</td>
<td>0.003</td>
<td>0.011</td>
<td>11000</td>
<td>22500</td>
<td>0.4889</td>
<td>3.00</td>
<td>0.162</td>
</tr>
<tr>
<td>12</td>
<td>8.424</td>
<td>0.001</td>
<td>0.012</td>
<td>12000</td>
<td>22500</td>
<td>0.533</td>
<td>3.46</td>
<td>0.154</td>
</tr>
<tr>
<td>16</td>
<td>8.425</td>
<td>0.001</td>
<td>0.013</td>
<td>13000</td>
<td>22500</td>
<td>0.5778</td>
<td>4.00</td>
<td>0.1445</td>
</tr>
<tr>
<td>20</td>
<td>8.427</td>
<td>0.002</td>
<td>0.014</td>
<td>14000</td>
<td>22500</td>
<td>0.622</td>
<td>4.47</td>
<td>0.139</td>
</tr>
<tr>
<td>25</td>
<td>8.429</td>
<td>0.002</td>
<td>0.016</td>
<td>16000</td>
<td>22500</td>
<td>0.711</td>
<td>5.00</td>
<td>0.142</td>
</tr>
</tbody>
</table>

Sorptivity = 0.1294 mm / min$^{0.5}$

4. Test Discussions

- As per IS code 17452: 2020, $\text{SiO}_2/\text{Na}_2\text{O}$ trials from 0.6–1.5 for mix proportion of Flyash: GGBS: Eggshell test conducted on mechanical properties and Acid attack tests on Geo-polymer Concrete on various days like 7, 28, 56, and 90 days were examined. From that, we explained the values in the mix proportion of $\text{SiO}_2/\text{Na}_2\text{O}$ on 1.3 we get the highest value of 43Mpa and the lowest value on $\text{SiO}_2/\text{Na}_2\text{O}$ of 0.6 is 36 Mpa.

- In the various mix proportion of $\text{SiO}_2/\text{Na}_2\text{O}$, the test conducted results on compressive strength on Geo-polymer concrete of Fly ash: Bauxite: Eggshell = 160Kg: 120Kg: 120 Kg were got on $\text{SiO}_2/\text{Na}_2\text{O} = 0.6$ is 9 Mpa for 7 days, 18 Mpa for 28 days, 33 Mpa for 56 days and 36 Mpa for 90 days.

- In the various mix proportion of $\text{SiO}_2/\text{Na}_2\text{O}$, the test conducted results on compressive strength on Geo-polymer concrete of Flyash: Bauxite: Eggshell = 160Kg: 120Kg get on $\text{SiO}_2/\text{Na}_2\text{O} = 0.8$ is 10 Mpa for 7 days, 19 Mpa for 28 days, 34 MPa for 56 days and 37 MPa for 90 days.

- In the various mix proportion of $\text{SiO}_2/\text{Na}_2\text{O}$, the test conducted results on compressive strength on Geo-polymer concrete of Fly ash: Bauxite: Eggshell = 160Kg: 120Kg were got lowest value on $\text{SiO}_2/\text{Na}_2\text{O} = 1.1$ is 11 MPa for 7 days, 20 MPa for 28 days, 36 MPa for 56 days and 39 MPa for 90 days.

- In the various mix proportion of $\text{SiO}_2/\text{Na}_2\text{O}$, the test conducted results on compressive strength on Geo-polymer concrete of Fly ash: Bauxite: Eggshell = 160Kg: 120Kg were got lowest value on $\text{SiO}_2/\text{Na}_2\text{O} = 1.3$ is 15 MPa for 7 days, 23 MPa for 28 days, 39 MPa for 56 days and 43 MPa for 90 days.

- In the various mix proportion of $\text{SiO}_2/\text{Na}_2\text{O}$, the test conducted results on compressive strength on Geo-polymer concrete of Fly ash: Bauxite: Eggshell = 160Kg: 120Kg: 120Kg were got lowest value on $\text{SiO}_2/\text{Na}_2\text{O} = 1.5$ is 14 MPa for 7 days, 22 MPa for 28 days, 38 MPa for 56 days and 42 MPa for 90 days.
The enhanced qualities of geopolymer concrete. As interatomic-bonding in the matrix. The system's intermolecular forces are therefore seen to be a plausible explanation for Ca-O-Si, and Si-O-Si, makes Mg + + present in the polymeric chain giving chemical stability or what is commonly referred to as a strong intermolecular connection thanks to the chemical makeup of magnesium, as seen in Figs. 9a and 9b.

In the various mix proportions of Geo-polymer concrete in the Flyash: GGBS: Eggshell powder (40:30:30) was explaining about the XRD images of mix proportions SiO2/Na2O = 1.1 and 1.2

To better understand the potential transformation in both the initial supplies and the samples subjected to high temperatures, an XRD technique was employed. The geo-polymer concrete XRD analysis results at ambient temperatures are shown in Fig. 8. The sample contained semi-crystalline Alumina-silicate gel (N-A-S-H) appearances. Due to an XRD peak, N-A-S-H is referred to as semi-crystalline. Alumina-silicate gel (N-A-S-H) appearances have been reported. Our investigation validates their findings that the geopolymer concrete component's broad peaks may be seen between 25 and 30° to the intensity of 2θ. Traces of C-S-H, N-S-H, and C-H were discovered after exposure [25]. The C-S-H gel, CH, and calcium carbonate have been regarded and identified as the core elements in this concrete. Rashad and Zeedan have also identified C-S-H-gel, which is mostly dominated by the presence of CH and calcite alongside CH and calcium carbonate. (C). Due to the CH's partial transformation to calcium carbonates including calcite and anorthite as well as its disintegration to quicklime (CaO), the CH peak's strength went down. It was anticipated to be primarily caused by the conversion of a novel structure to the crystalline anhydrous calcium silicate phases calcite (C) and anorthite (An) [26].

In the various mix proportions of Geo-polymer concrete in the Flyash: GGBS: Eggshell powder (40:30:30) we are explaining from the Fig. 9a and 9b FTIR images of SiO2/Na2O = 1.1 and 1.3. Figures 9a and 9b depict the FTIR spectra of Geo-polymer concrete that has been 90 days old and cured at ambient temperatures. Numerous bands and functional categories created during polymerization are what distinguish the different absorption frequencies of the Geo-polymer products. The bands between 3300 and 3600 cm⁻¹ showed that there is an O-H bending stretching vibration. While the bands at 2000–2200 cm⁻¹ could correspond to the stretching vibration of a functional group comprised of Na₂CO₃, K₂CO₃, or sodium phosphate that was formed during the polymerization process by the activator solution and the binder substance. A part of the excess sodium ions is often carried to the surface where it carbonates with the carbon dioxides if there is an excess due to the high concentration of alkali solution [27]. CaO could contain a stretching vibration frequency of 2500 cm⁻1. The HO-H group may be seen in the bands at 1670 cm⁻¹. At the peaks 1470 cm⁻¹, the frequencies of CO₂⁻ with CO group stretching vibrations were determined. The asymmetric and symmetric stretching vibrations of Si-O-Si and Al-O-Si, which are created during the dissolution of SiO4 tetrahedral, are responsible for the broadband at around 940–1005 cm⁻¹. Typically, the bands centered in these regions correlate to the C-S-H gel. The stretching vibration of CO3 was measured at 875 cm⁻¹, whereas the bands Si-O and Al-O were subjected to stretching at 850 cm⁻¹. [27]. The mechanical and microstructural properties of the GP concrete mixed with FA, GGBS, and eggshell powder have been evaluated shown to have enhanced in this study. Due to the occurrence of various chemical reactions in the mixture brought caused by the presence of the alkali activator solution, the combination of those three ingredients produced ternary gel phases. Additionally, it was shown that when compared to the A-S-H and C-S-H gels made from FA and GGBS, the M-S-H or CM-S-H gel derived from eggshell powder is denser and morphologically less porous. It is readily apparent that adding eggshell powder to class F FA and GGBS significantly improves their technical qualities [25, 27].

The polymeric system's polymerization is aided by the Mg + + cations from the GGBS source. By swapping oxygen atoms with other cations like Si + 4 and Al + 3, the Mg + + cations are able to create a strong intermolecular connection thanks to the chemical makeup of magnesium, as seen in Figs. 9a and 9b. That and the suggested paradigm in Fig. 9 are essentially related. Further, the occurrence of various chain links, such as Si-O-Mg, Si-O-Al, Ca-O-Si, and Si-O-Si, makes Mg + + present in the polymeric chain giving chemical stability or what is commonly referred to as interatomic-bonding in the matrix. The system's intermolecular forces are therefore seen to be a plausible explanation for the enhanced qualities of geopolymer concrete. [27].
In the various mix proportions of Geo-polymer concrete in the Flyash: GGBS: Eggshell powder (40:30:30) we talk about the Geo-polymer concrete SEM photographs. From Fig. 10 SiO₂/Na₂O = 1.1 and 1.3 in various microns, we extrapolated that the white portions are un-hydrated particles, the black parts are holes or fractures, and the dark grey regions are CH, C-S-H, and other hydration products. The SEM micrograph image now illustrates that multiple white and black spots signifying voids, cracks, and un-hydrated products have been observed in the images. The dark shadow of the concrete in the other colour area in the photograph demonstrates the discontinuity and non-homogeneity of the concrete, which displays reduced compressive strength [23]. When correlated to other items, the SEM micrographs which encompass many white regions recommend the un-hydrated products. They also indicate a minor enhancement of compressive strength. While the evidence implies that the internal grains are tightly packed and that the solid mass is comprised of a firm solid that is tightly consolidated, there are deviations. The white and black regions of the concrete cube of blended mix reflected the indication of un-hydrated products and voids/cracks in the geo-polymer concrete. According to states, the areas’ dark grey shades are hydrated products. [23]. Now, in the SEM micrographs, a portion of the black region depicts small gaps or fissures, while a portion of the white area displays un-hydrated particles. In addition, we learn that the use of hydration products altered a lot of grey spots into dark grey ones. Last but not least, it is simple to spot several dark patches and spherical forms when recognizing un-hydrated items with voids/cracks. This depicts the decrease in compressive strength from Fig. 10 depiction [23].

5. Conclusions

In the present study, experimental research on the microstructural and mechanical properties of FA-GGBS- Eggshell powder-based geopolymer concrete was carried out. On the compressive strength of the geo-polymer concrete, the effects of supplementing some of the FA with GGBS and eggshell powder were investigated. With a compressive strength of 43.6 MPa and durable qualities of geo-polymer concrete employing HCL and H₂SO₄ solution, it transpired that geo-polymer concrete combined with 40% FA, 30% GGBS, and 30% eggshell powder displayed higher mechanical properties. There are more crystalline phase formations, according to the morphological and microstructural assessments. These originated from a number of substances, notably Ca, Mg, Si, Al, and Na, employing EDX-XRF. The results of XRD demonstrated the emergence of novel gel phases including C-S-H, C-A-S-H, and others. The produced Geo-polymer concrete has an immovable matrix, less porosity, and is enormously compacted, according to the SEM study. The partial replacement of FA with GGBS and eggshell powder heightens the mechanical characteristics of the generated GPC, according to the EDX-XRF analysis in conjunction with SEM images and FTIR data. This is mostly caused by the crystalline phases that have formed as a result of the addition of Ca ++ and Mg ++ to the Geopolymer gel. Due to the development of ternary gels C-S-H, A-S-H, and Na-Al (Mg)-Si-H from the combination of FA, GGBS, and Eggshell powder, the mechanical properties of the ensuing geo-polymer products are improved. By emphasis on two potential solutions, this paper emphasizes present research that includes the evolution of geopolymer concrete technology. First, it might make use of industrial leftovers and lessen the supply of hazardous debris. Second, it can be used as an alternative source of cementitious material that is less harmful to the environment than typical concrete.

Declarations

Conflict of interest

The purpose of the study in this article is to look into the feasibility of generating new geopolymer concrete from waste by-products. (FA, GGBS and Eggshell powder). These substances pollute the soil, have adverse impacts on the environment and also cause greenhouse gases. The aforementioned environmental issues are resolved by using these components in geopolymer concrete, which also exemplifies that concrete may be an OPC substitution. In the recent past, the subject has seen a lot of study activity. This study illustrates that, when compared to traditional concrete, geopolymer concrete has higher mechanical and microstructural attributes.
References


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Figures

**pH value Ranges**

![Figure 1](image1)

**pH value of Flyash, Eggshell, GGBS, RGL**
Figure 2

a, b: Reaction generating Liquid

Figure 3

a – Flyash, 3b – GGBS and 3c - Eggshell powder
Figure 4

a – Flyash, Fig 4b – GGBS and Fig 4c - Eggshell powder

Fly ash : GGBS : Eggshell = (40:30:30)

Figure 5

Fly ash: GGBS: Eggshell = (40:30:30)
Figure 6

Flyash: GGBS: Eggshell = (40:30:30) \( H_2SO_4 \) Solution = 5%, HCL Solution = 5%

Figure 7

Flyash: GGBS: Eggshell = (40:30:30)
XRD – Studies on Geo-polymer concrete

Figure 8

XRD Graphs on Geo-polymer concrete

FTIR - Studies on Geo-polymer concrete

Figure 9

a and 9b: FTIR Graphs on Geo-polymer concrete
Figure 10

SEM Micrographs of Geo-Polymer concrete mix