Effect of Molarity of Sodium Hydroxide Solution Over GGBS-based Self Compacting Geopolymer Concrete

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Abstract. Applications of geopolymer concrete are increasing at a faster rate globally and are actively replacing cement concrete in all its facets. Regarding this, the advancement of, self-compacting geopolymer concrete is inevitable. The present study deals with the investigation of the effect of the molarity of sodium hydroxide solution that is to be used as part of an alkaline solution, over self-compacting and hardened properties of geopolymer concrete. Ground granulated Blast Furnace Slag (GGBS) is used as precursor material; hence, ambient curing is adopted. The alkaline activator solution is a combination of silicate solution and hydroxide based on sodium. In this work, the hydroxide solution's molarity is varied to 8, 10, 12, 14, 16, and 18. Self-compacting properties are investigated through spread flow, T-50, V-funnel test, and L-box. The compressive strength of the hardened concrete is investigated over 7 and 28 days. Further water absorption test was also assessed in this investigation to determine the basic durability. All the specimens with different molarities exhibited fair self-compacting properties. Further optimum molarity required for the synthesis of self-compacting geopolymer concrete with fair compressive strength and excellent reduced water absorption capability is determined. The findings of this work tend to augment significant contributions to the geopolymer concrete in the facets of self-compacting nature.

1 Introduction

One of humanity's greatest tools for survival, concrete has helped build homes for billions of people. It is a blend of aggregates with precise sizing in a cementitious base that is very strong, long-lasting, and workable. However, the widespread use of concrete has disastrous repercussions on the environment as a result of growing urbanization, industrial expansion, and robotization. Clinker, which is produced by heating limestone to extremely high temperatures, is used to make cement. Carbon-based fuels are used to provide this heat, however, doing so results in significant environmental harm from CO2 emissions [1]. Profuse research indicates that cement manufacturing emits 0.62 to 0.82 kg of CO2 in various forms.
throughout the process [2, 3]. Hence a technology reducing the use of carbon fuel and emission of CO2 or replacing cement is a sustainable option. Therefore, a number of studies concentrate on utilizing industrial wastes to create geopolymer concrete, including fly ash, wood ash, biomedical ash, and ground and granulated blast furnace slag (GGBS). [4–6].

As the concept of geopolymer concrete implements the replacement of cement with industrial wastes, it economically reduces CO2 emission thus giving a long-term alternative to traditional cement concrete and also an effective solution to industrial by-product disposal. The chemical interaction between aluminosilicate source materials such as fly ash, GGBS, metakaolinite, etc., produces geopolymers, where the oxygen and aluminium atoms create a Four-hedral structure (tetrahedral chain) of SiO3 and AlO4 sharing the oxygen atoms alternatively[7,8]. The alkaline solution, such as a solution of sodium hydroxide and silicate, activates the silicate and aluminate atoms to form the geopolymer network, which allows a bond to form between the aggregates and the inert materials. [8,9]. Geopolymers prepared from low calcium types like low calcium fly ash yield fair engineering properties, better temperature properties, and reduced drying shrinkage and creep [10–12]. Geopolymer concrete needs high curing temperatures ranging from 80oC to 120oC for a duration of 4 to 20 hours [12, 13]. However, the variations in curing temperature are mainly influenced by the physical and chemical properties of fly ash as well as the chemical composition of the activators [14, 15]. GGBS-based geopolymer concrete enables the concrete to gain strength under ambient curing conditions with appreciable durability properties [16–18].

Ground and granulated blast furnace slag (GGBS) is a by-product of iron production using blast furnaces. GGBS has a high concentration of calcium and silica which makes it carry both qualities of pozzolan and cement, making it a preferred material in the construction industry in the preparation of modified and improved concrete that is more durable with enriched mechanical properties [19]. It has been reported that the addition of GGBS alters the microstructure, thus altering the durability of the alkali-activated concrete [20, 21]. The raw materials used in the production of iron determine the chemical composition of GGBS, while the cooling process used to cool down the molten materials determines the physical properties. The cooling method involves rapid cooling of the molten material, either by quenching in water using a high-pressure water jet to create amorphous GG particles or by pelletization. Despite the slight differences in its composition, GGBS helped to fill pores and led to the evolution of unvarying microstructures with a high arrangement and synergistic products consisting of highly polymerized alkaline units and gels of calcium silicate hydrate (C-S-H). Evidence currently available indicates that GGBS increases the solubility of Ca and enhances the amorphyosity and inhomogeneity of products. Additionally, the creation of N(C)-A-H C-S-H and products of Na/Ca -aluminosilicate-hydrate improves concrete compressive strength [22–24].

Self-compacting concrete [self-consolidating concrete] is one of the advanced concrete technologies being used in high-rise concrete structures, because of its remarkable deformability, high resistance to segregation, and successful application in congested reinforced concrete structures that are characterized by challenging casting conditions that restrict vibration [25]. A high flow ability and a high resistance to segregation are two characteristics of SCC, which Professor Okumura was the first person to investigate and establish in 1988. Under its own weight, this property can be utilized for the purpose of filling in formwork without the utilization of vibrators or any other mechanical means. [26]. Extending the geopolymer concrete with the self-compacting concrete is a less researched area in the vicinage of geopolymer concrete. A relatively limited amount of studies have been conducted to investigate the impact that the presence of slag has on the fresh, mechanical,
and durability behaviours of materials, as well as on the predictive models of mechanical properties.

When it comes to achieving good consolidation, adequate compaction of fresh concrete is essential, hence vibration is necessary for optimal compaction for regular geopolymer concrete. The alternative is self-compacting concrete (SCC), which fills every corner of the formwork under its weight and does not require any way of compacting. SCC provides a number of advantages, including the ease with which concrete can be filled in confined spaces, increased compaction, strong bond strength with reinforcement, reduced maintenance requirements, faster construction rates, improved concrete quality, and reduced overall building costs of the building. The production of new concrete that possesses the benefits of both types of concrete is encouraged by the advantages of geopolymer technology as well as the growing trend of construction industries towards SCC. As a result of the development of SCGC, there is no need for any kind of compaction, and the use of Portland cement is also eliminated. Self-compacting geopolymer concrete combines SCC and GC’s properties, thus providing us with a better environment-friendly SCC.

Hefty research works are concentrated in the vicinity of self-compacting concrete and alkali-activated concrete discretely. But only a few research works, deal with the cement less self-compacting concrete (Manjunath). Since GGBS are primarily used as the binder material, the need for heat curing is eliminated in this investigation. This article fills a research gap by investigating the effect of the molarity of activator solution over the self-compacting properties, compressive strength, and water absorption in geopolymer concrete. Filling ability and passing ability are the important parameters to be considered as self-compacting concrete. The outcomes from this research work tend to supplement significant contributions to the geopolymer concrete in the facets of its self-compacting nature.

2 Experimental Investigation

2.1 Materials

The materials utilized in this study comprise Ground Granulated Blast Furnace Slag (GGBS) as the binder substance and a amalgamation of (Na) sodium based hydroxide (NaOH) and silicate solution (Na2SiO3) as the AAS which are procured from a local supplier in Chennai. M-sand is used as the fine aggregate and 20mm close by available gravels are employed as the coarse aggregate. The properties of coarse and fine aggregates confirms to IS 383[27]. In addition, ether polymer-based poly-carboxylic is used as the superplasticizer. The properties of the superplasticizer are in accordance with IS 9103[28]. Table 1 lists the physical characteristics of materials used in this investigation.

<table>
<thead>
<tr>
<th>Material</th>
<th>Specific Gravity</th>
<th>Fineness Modulus</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>GGBS</td>
<td>2.9</td>
<td>Na</td>
<td>Na</td>
</tr>
<tr>
<td>Fine aggregate</td>
<td>2.6</td>
<td>2.85</td>
<td>Na</td>
</tr>
<tr>
<td>Coarse aggregate</td>
<td>2.82</td>
<td>6.6</td>
<td>Na</td>
</tr>
<tr>
<td>Superplasticizer</td>
<td>1.12</td>
<td>Na</td>
<td>7</td>
</tr>
<tr>
<td>Sodium Hydroxide (NaOH)</td>
<td>1.4</td>
<td>Na</td>
<td>Na</td>
</tr>
<tr>
<td>Sodium Silicate (Na2SiO3)</td>
<td>1.67</td>
<td>Na</td>
<td>Na</td>
</tr>
</tbody>
</table>
2.2 Preparation of Alkali Activated Solution

Alkaline activator solution consists of NaOH and Na2SiO3. Sodium hydroxide solution is made 24 hours before the casting of specimens. NaOH flakes of 98 percent purity are dissolved in distilled water in a beaker. The quantities of mixing for different molarities are tabulated in Table 2. Since the reaction is exothermic, it involves the liberation of heat. The solution is stored in a borosil bottle to prevent melting and is stored safely.

Table 2. Mix Design of SCGC

<table>
<thead>
<tr>
<th>Mix ID</th>
<th>GGBS (kg/m3)</th>
<th>M-sand (kg/m3)</th>
<th>Gravel Stones (kg/m3)</th>
<th>NaOH (kg/m3)</th>
<th>Na2SiO3 (kg/m3)</th>
<th>Molarity</th>
<th>Solid NaOH (kg)</th>
<th>Distilled Water (kg)</th>
<th>Superplasticizer (kg/m3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCGC8</td>
<td>500</td>
<td>750</td>
<td>750</td>
<td>95.86</td>
<td>239.64</td>
<td>8</td>
<td>24.44</td>
<td>71.42</td>
<td></td>
</tr>
<tr>
<td>SCGC10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10</td>
<td>29.33</td>
<td>66.53</td>
<td></td>
</tr>
<tr>
<td>SCGC12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>12</td>
<td>31.73</td>
<td>64.13</td>
<td></td>
</tr>
<tr>
<td>SCGC14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>14</td>
<td>38.34</td>
<td>57.52</td>
<td></td>
</tr>
<tr>
<td>SCGC16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>16</td>
<td>42.47</td>
<td>53.39</td>
<td></td>
</tr>
<tr>
<td>SCGC18</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>18</td>
<td>46.49</td>
<td>49.37</td>
<td></td>
</tr>
</tbody>
</table>

2.3 Methodology

The experimental methodology involves the casting of self-compacting geopolymer concrete specimens. Since there is no set of standards involved in the mix design of SCGC, a trial mix is adopted based on the past investigation by the author. The mix quantities of different mixes are tabulated in Table 2. The molarity of sodium hydroxide solution is the only variable in the mixes as the investigation focuses over the influence of molarity over the fresh and hardened characteristics of SCGC. Initially, dried aggregates and GGBS are blend in the mixer for a period of 5 minutes trailed by the incorporation of an alkali solution. The mixing is continued for approximately 3 minutes and finally, the superplasticizer is added and mixed for about 5 minutes till it achieves homogeneity. The freshly prepared specimen is then subjected to passing ability and filling ability tests before casting into moulds. Filling and passing ability are the significant parameters to be considered as self-compacting concrete. Filling capability is determined through the spread flo and V-funnel test. Filling ability is evaluated through the L-Box test. The concrete is then cast into 150mm cubical specimens for determining the compressive strength and water absorption capacity. The hardened specimens are exposed to ambient curing for seven days and twenty eight days depending on the test period. Under ambient curing conditions, the temperature was between 36 to 41 degree Celsius.

3 Results and Discussions

3.1 Slump Flow

The filling ability of SCGC can be investigated through slump flow test. Slump flow is a measure of the consistency or flow of concrete. In addition to slump flow, T50 is also
determined through this test. The amount of time period needed for the mix to spread to till 500 mm is also determined. The influence of the molarity of AAS over the flow of slump is investigated in this test and the values are presented in tabular form in Table 3.

Table 3. Passing ability and Filing Ability of Self Compacting Specimens

<table>
<thead>
<tr>
<th>Mix ID</th>
<th>Slump flow Spread (mm)</th>
<th>V-Funnel T50 (Sec)</th>
<th>L-Box T (Sec)</th>
<th>Blocking ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCGC8</td>
<td>780</td>
<td>4.2</td>
<td>6.5</td>
<td>0.95</td>
</tr>
<tr>
<td>SCGC10</td>
<td>765</td>
<td>4.55</td>
<td>7.2</td>
<td>0.93</td>
</tr>
<tr>
<td>SCGC12</td>
<td>720</td>
<td>4.85</td>
<td>7.5</td>
<td>0.90</td>
</tr>
<tr>
<td>SCGC14</td>
<td>680</td>
<td>5.17</td>
<td>8.2</td>
<td>0.87</td>
</tr>
<tr>
<td>SCGC16</td>
<td>660</td>
<td>5.60</td>
<td>9.4</td>
<td>0.83</td>
</tr>
<tr>
<td>SCGC18</td>
<td>600</td>
<td>6.3</td>
<td>9.8</td>
<td>0.81</td>
</tr>
</tbody>
</table>

Table 3 clearly states that the mix SCGC8 unveils the maximum spread and minimum duration for the spread of 500 mm whereas specimen SCGC18 exhibits the minimum spread and maximum time for the spread to 500mm. The slump flow decreases with the raise in according to the molarity of the Sodium Hydroxide (NaOH) solution and the T50 value increases with the raise in the molarity of the NaOH solution.

The reason for the increase in flow spread and decrease in time taken for the spread to reach 500mm with the raise in the molarity is the improved consistency of NaOH solution. When molarity increases, the concentration of NaOH also rises that eventually improves the consistency of the concrete. Acceptable values for the spread of slump flow vary from 650 mm to 800 mm and T50 varies from 2 sec to 5 sec as per EFNARC guidelines. However, all the SCGC specimens exhibited fair filling ability within the limits.
3.2 V-Funnel

The second method of assessing the filling capability of SCGC is through the V-Funnel test. The influence of the molarity of AAS over the flow of slump is investigated by determining the time taken for SCGC to completely drain out from the V-funnel and the values are listed in tabulation form in Table 3.

From Table 3, Specimen SCGC8 exhibits the minimum passing capacity, and SCGC 18 exhibits the slowest passing capacity. It is explicit that the time taken for the SCGC to completely drain from V-Funnel raises with improves in the molarity of NaOH solution. Also, all the SCGC mixes with varied molecular weight of NaOH solution exhibited fair filling ability. As per EFNARC guidelines acceptable V-Funnel test values range from 6 to 12. The values of the V-Funnel test are in accordance with the slump flow test.

3.3 L-Box

The passing capacity of SCGC is investigated utilizing the L-Box test, an investigation into the passing capacity of SCGC is carried out. The L-Box test. The influence of the concentration of AAS over the ability of passing is investigated in this test and the values are tabulated in Table 3.

From Table 3, it is implied that specimen SCGC8 exhibits the minimum filling capacity, and SCGC 18 exhibits the slowest filling capacity. From Table 3, evidently, it is clear that the blocking ratio of SCGC decreases with the raise in the concentration of the hydroxide solution. All the specimen exhibits a blocking ratio of more than 0.8 satisfying the requirements of self-compacting concrete. At lesser molarity, the ability of the self-compacting concrete to fill congested places is good whereas the same capacity reduces with the augmentation in the concentration of AAS.

3.4 Compressive Strength

The Important aspect for any material to replace concrete is compressive strength. The adverse effect of NaOH molarity over SCGC is investigated in this test and the achieved values are tabulated in Table 4.

<table>
<thead>
<tr>
<th>Mix ID</th>
<th>Compressive Strength (MPa)</th>
<th>Water Absorption</th>
<th>Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7 days</td>
<td>28 days</td>
<td>Initial Capacity (%)</td>
</tr>
<tr>
<td>SCGC8</td>
<td>37.6</td>
<td>43.6</td>
<td>1.2</td>
</tr>
<tr>
<td>SCGC10</td>
<td>40.2</td>
<td>45.3</td>
<td>1.4</td>
</tr>
<tr>
<td>SCGC12</td>
<td>42.8</td>
<td>47.7</td>
<td>1.2</td>
</tr>
<tr>
<td>SCGC14</td>
<td>42.4</td>
<td>46.4</td>
<td>1.3</td>
</tr>
<tr>
<td>SCGC16</td>
<td>41.3</td>
<td>44.5</td>
<td>1.6</td>
</tr>
<tr>
<td>SCGC18</td>
<td>36.8</td>
<td>40.2</td>
<td>1.9</td>
</tr>
</tbody>
</table>

It is deduced from Table 4 that SCGC12 shows the highest characteristic strength and specimen SCGC18 yields the least characteristic strength. Also, all the SC specimens exhibited about 89% of the 28 days strength in 7 days. It is inferred that there is an increase in characteristic strength with the increase according to the molarity of the NaOH solution till 12 molarity beyond which it decreases.
The increase in compressive strength till 12M is due to the increased availability of hydroxide ions at increased concentrations. The increase in molarity is due to the increased polymerization reaction [15]. A decrease in strength is observed after 12 M. One day before casting, the liquid-alkaline combination was produced. During preparation, it was seen that precipitation occurs and salts settle to the bottom of the beaker as the molarity rises over 14. One of the main causes of the strength's decline after 14M was due to this. The mixture was more viscous and challenging to compact at 14M. This problem of a highly viscous nature may be the cause of the decline in strength.

### 3.5 Water Absorption

The water absorption of material is an essential property because it can affect the strength and durability of the material. Concrete having low water absorption is generally more durable and has a higher strength than concrete with high water absorption. The standard for water absorption of concrete is the amount of water that a concrete sample will absorb when immersed in water for a specific period of time. It is performed in accordance with ASTM C642 [29]. The effect of molarity of NaOH over SCGC is investigated in this test and the values are listed in Table 4.

From Table 4, it is pragmatic that specimen SCGC12 exhibits the minimum water absorption capacity. However, all SCGC specimens exhibited excellent water absorption characteristics.
as per ASTM standards. Water absorption characteristic tends to decrease till 12 molarity and then it increases. The initial decrease in water absorption capacity till 12 M corresponds to a finer matrix leading to reduced porosity. Manjunath et al., [30] also reported a reduction in water absorption capacity till the optimum molarity due to the improved microstructure. SCGC specimens with a molarity more than 12 molarity are observed to yield comparatively higher water absorption capacity owing to the comparatively less dense microstructure. The water absorption property of specimens increases with the falls in the compressive strength and vice versa.

4 Conclusion

From the extensive investigation, the succeeding summarizations can be made

- Passing ability of slag-based SCGC specimens reduces with the raise according to the molarity of the NaOH solution.
- Filling ability of slag-based GCGC specimens reduces according to the molarity of the NaOH solution.
- All the SCGC specimens exhibited passing ability and filling ability standards required for the self-compacting concrete.
- Compressive strength augmented with the raise in the molarity of solution till 12 molarity and beyond that, it decreases. The rate of gaining of compressive strength of SCGC specimens for 7 days increased with the raise in the molarity of the AAS.
- Both initial and final Water absorption capacity decreased with the raise according to the molarity of the NaOH solution till 12 molarity and above that, it increases. All the specimens exhibited excellent standards as per ASTM specifications.
- Optimum molarity was determined as 12 molarity for the NaOH solution to be utilized as the AAS for the synthesis of self-compacting geopolymer concrete.

References


