

A Study on Wood Ash Based Lye as Alkaline Activator in Geopolymer Concrete

Nagaraj. V. K¹, Puttaswamy. B. K²

P.G. Student, Dept. of Civil Engineering, Sri Venkateshwara College of Engineering, Bengaluru, Karnataka, India¹

Assistant Professor, Dept. of Civil Engineering, Sri Venkateshwara College of Engineering, Bengaluru, Karnataka, India²

ABSTRACT: Geopolymers uses alkaline activator such as silicates of potassium or sodium and hydroxides of potassium or sodium along with industrial by products like GGBS etc. The activator undergoes geopolymerization and then reacts with by-products and produces binding property for the matrix. In this study GGBS is used as filler and combination of Lye (Potassium hydroxide Lye) solution and sodium silicate are used as alkaline activator liquids. Basically the replacement of sodium hydroxide from the matrix results in reduction of cost, hence an attempt is made to generate a suitable material in place of hydroxides of sodium or potassium. The Lye which is leached from the waste wood ash on mixing it with distilled water for about three days, can be effectively used to produce Economized geopolymer concrete which satisfies the fresh and hardened properties same as geopolymer concrete.

KEYWORDS: Geopolymer, geopolymerization, GGBS, lye, reduction of cost.

I. INTRODUCTION

In construction, to arrest the environmental pollution an alternate source of binding material in place of cement concrete should be used, Geopolymer concrete could be the answer. Technology was first proposed by a French Professor Joseph Davidovits in 1978. Geopolymers are members of inorganic family which forms mineral molecular chains linked with co-valent bonds by making use of alkaline activators and industrial by-products. Chemical composition of geopolymer is same as zeolite and its nature of structure is amorphous, the alumina and silica present in industrial by-products (GGBS) reacts with alkaline liquid and produces binding property. Alkaline liquid used are combination of sodium hydroxide or potassium hydroxide and sodium silicate or potassium silicate is most common. The filler material in geopolymer concrete can be a waste industrial by-product and alkaline activators which are commercially available are of high cost which makes geopolymer concrete uneconomic compare to conventional concrete. Geopolymer concrete are at its best with workability, strength and resistance to attack from chemicals when compared to conventional concrete. According to Joseph Davidovits, geopolymeric materials have various applications in different industries such as in plastic industries, aerospace industries, automobile industries, etc. In spite of all its advantages, lack of instructions to prepare and use are making geopolymer concrete as a history.

II. RELATED WORK

As per our literature review, this is the first time that Lye leached with waste wood ash is being used as an alkaline activator in producing geopolymer concrete.

III. SCOPE OF WORK

The scope of this project is to study the properties of ground GGBS and wood ash leached Lye as an activator on geopolymer concrete. The cost of activators like hydroxides used to produce ordinary geopolymer concrete is high. Hence to reduce the cost of geopolymer concrete hydroxides of potassium or sodium is replaced by Lye which is leached by using waste wood ash, wood ash as a waste product is effectively used in generating high pH activator known as Lye, which can be named as an Economized geopolymer concrete.

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IV. OBJECTIVES OF WORK

- Using Potassium hydroxide Lye leached with waste wood ash as alkaline liquid to generate Economized geopolymer concrete.
- Studying the fresh and hardened properties.
- Minimizing cost and human ill effects caused by other hydroxide activators.
- To establish an optimum mix design.

V. MATERIALS REQUIRED

Economized geopolymer concrete mainly uses GGBS, lye, sodium silicate, fine aggregate and coarse aggregate.



Fig.1 GGBS

Fig.2 Lye

Fig.3 Sodium silicate



Fig. 4 Fine aggregate(river sand) Fig.5 Coarse aggregate (12.5mm)

VI. EXPERIMENTAL WORK

A. Preparation of Lye.

- Distilled water is filled in a barrel or a container. The purer the water, the more lye can be leached from ashes.
- Waste wood ash is collected and scooped out into the barrel containing distilled water.
- Put the barrel on a safe base someplace where it remains undisturbed, let the ash soak for 3 days.
- After 3 days, feather test is conducted. In this test generally a bird feather is dipped in wood ash water, if the delicate portion of feather dissolves in the water then the Lye is ready to use, if it does not dissolves then extra ash should be added to the wood ash water at regular intervals until Lye is leached.
 - Once the Lye is leached from waste wood ash water, filter and remove suspended particles from waste wood ash water, the waste wood water free from suspended and settled wood particles is Lye.
 - In this research work Lye was generated on 15th day.



Fig.6 Waste wood ash collected from different places



Fig.7 Scooping of waste wood ash into distilled water



Fig. 8 Leached Lye



Fig.9 Filtration of Lye

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B. Mixing, casting and curing of Economized geopolymer concrete.

Conventional method of mixing, casting and curing was adopted. The fresh geopolymer concrete mix had a stiff consistency with a glossy appearance and was grey in colour. The alkaline activator liquid should be mixed uniformly and should be used after 24 hours and it must be used within 36 hours after mixing. The alkaline activator liquid is mixed with cementitious binder and aggregates on the day of casting of specimens .



Fig.10 Mixing of alkaline activators

VII. RESULTS AND DISCUSSIONS

A. Test on total solids

To check the total solid content in Lye this test is majorly preferred. The total solid content obtained is then made use in mix design of Economized geopolymer concrete. The apparatus used in finding the total solids are Crucible, heating mantle, weigh balance, measuring jar.

Procedure.

- Take clean empty crucible weight as w_1 .
- Pour the required amount of sample (25 ml) into it.
- Evaporate the sample to 100°C until entire liquid evaporates and only solid is left, take care that residue should not burn.
- Cool it using desiccators or keep it in cool place.
- Finally take the weight of sample left in residue as w_2 .

$$\text{Total solids} = \frac{(w_2 - w_1) \times 1000000}{\text{amount of sample taken}}$$

Calculations.

Empty weight of crucible (w_1) = 36.036 g

25 ml sample + crucible weight (w_2) = 36.610 g

$$\text{Total solids (mg/litres)} = \frac{(36.610 - 36.036) \times 1000000}{25} = 22960 \text{ mg/litres} = 0.02296 \text{ kg/liters}$$

Therefore, total solids in Lye is 0.02296 kg/litres

Percentage of total solids in Lye is 2.296%

B. Workability test results

(AA/CB stands for Alkaline Activator to Cementitious Binder ratio and AAR stands for Alkaline Activator Ratio)

Table.1 Workability test results.

| | Mix no. | AA/CB | AAR | Slump (mm) | Degree of workability as per IS 456:2000 |
|----------------------|----------------|-------|-----|------------|--|
| GPC ₁ mix | G ₁ | 0.4 | 2 | 160 | Very high |
| | G ₂ | | 2.5 | 200 | Very high |
| | G ₃ | | 3 | 240 | Very high |
| | G ₄ | | 3.5 | 270 | Very high |
| GPC ₂ mix | Mix no. | AA/CB | AAR | Slump (mm) | Degree of workability as per IS 456 : 2000 |
| | G ₅ | 0.45 | 2 | 140 | High |
| | G ₆ | | 2.5 | 160 | Very high |
| | G ₇ | | 3 | 210 | Very high |
| G ₈ | 3.5 | | 250 | Very high | |

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| GPC ₃ mix | Mix no. | AA/CB | AAR | Slump (mm) | Degree of workability as per IS 456:2000 | |
|----------------------|-----------------|-------|-----|------------|--|-----------|
| | G ₉ | 0.5 | | 2 | 140 | High |
| G ₁₀ | 2.5 | | | 180 | Very high | |
| G ₁₁ | 3 | | | 210 | Very high | |
| G ₁₂ | 3.5 | | | 240 | Very high | |
| GPC ₄ mix | Mix no. | AA/CB | AAR | Slump (mm) | Degree of workability as per IS 456 : 2000 | |
| | G ₁₃ | 0.55 | | 2 | 140 | High |
| | G ₁₄ | | | 2.5 | 170 | High |
| | G ₁₅ | | | 3 | 200 | Very high |
| | G ₁₆ | | | 3.5 | 220 | Very high |
| GPC ₅ mix | Mix no. | AA/CB | AAR | Slump (mm) | Degree of workability as per IS 456:2000 | |
| | G ₁₇ | 0.6 | | 2 | 120 | High |
| | G ₁₈ | | | 2.5 | 170 | High |
| | G ₁₉ | | | 3 | 190 | Very high |
| | G ₂₀ | | | 3.5 | 210 | Very high |

C. Compressive strength test results

Table.2 Compressive strength test results

| | Mix no. | AAR/CB | AAR | Compressive strength (MPa) | | |
|----------------------|-----------------|--------|-----|----------------------------|--------|---------|
| | | | | 3 days | 7 days | 28 days |
| GPC ₁ mix | G ₁ | 0.4 | | 2 | 34.33 | 43.67 |
| | G ₂ | | | 2.5 | 25.00 | 35.33 |
| | G ₃ | | | 3 | 20.67 | 23.17 |
| | G ₄ | | | 3.5 | 17.00 | 18.17 |
| | | | | | | |
| GPC ₂ mix | Mix no. | AAR/CB | AAR | Compressive strength (MPa) | | |
| | G ₅ | 0.45 | | 2 | 43.33 | 51.33 |
| | G ₆ | | | 2.5 | 38.33 | 43.67 |
| | G ₇ | | | 3 | 33.33 | 40.67 |
| | G ₈ | | | 3.5 | 23.67 | 32.67 |
| GPC ₃ mix | Mix no. | AAR/CB | AAR | Compressive strength (MPa) | | |
| | G ₉ | 0.5 | | 2 | 46.67 | 54.83 |
| | G ₁₀ | | | 2.5 | 39.00 | 45.67 |
| | G ₁₁ | | | 3 | 38.17 | 43.00 |
| | G ₁₂ | | | 3.5 | 26.5 | 32.00 |
| GPC ₄ mix | Mix no. | AAR/CB | AAR | Compressive strength (MPa) | | |
| | G ₁₃ | 0.55 | | 2 | 38.33 | 46.67 |
| | G ₁₄ | | | 2.5 | 37.33 | 38.00 |
| | G ₁₅ | | | 3 | 32.67 | 35.33 |
| | G ₁₆ | | | 3.5 | 21.67 | 22.67 |
| GPC ₅ mix | Mix no. | AAR/CB | AAR | Compressive strength (MPa) | | |
| | G ₁₇ | 0.6 | | 2 | 41.17 | 52.33 |
| | G ₁₈ | | | 2.5 | 32.83 | 45.33 |
| | G ₁₉ | | | 3 | 30.67 | 43.33 |
| | G ₂₀ | | | 3.5 | 22.33 | 32.33 |

D. Split tensile test results

Table.3 Split tensile strength test results

| | Mix no. | AA/CB | AAR | Split tensile strength (MPa) | | |
|----------------------|----------------|-------|-----|------------------------------|--------|---------|
| | | | | 3 days | 7 days | 28 days |
| GPC ₁ mix | G ₁ | 0.4 | | 2 | 3.97 | 4.19 |
| | G ₂ | | | 2.5 | 3.63 | 3.81 |
| | G ₃ | | | 3 | 2.98 | 3.43 |
| | G ₄ | | | 3.5 | 3.11 | 3.40 |

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| | Mix no. | AA/CB | AAR | Split tensile strength (MPa) | | |
|----------------------|-----------------|-------|-----|------------------------------|--------|---------|
| | | | | 3 days | 7 days | 28 days |
| GPC ₂ mix | G ₅ | 0.45 | 2 | 4.11 | 4.64 | 4.98 |
| | G ₆ | | 2.5 | 4.06 | 4.44 | 4.79 |
| | G ₇ | | 3 | 3.89 | 4.23 | 4.67 |
| | G ₈ | | 3.5 | 3.19 | 3.87 | 4.09 |
| | | | | | | |
| GPC ₃ mix | G ₉ | 0.5 | 2 | 5.00 | 5.11 | 5.59 |
| | G ₁₀ | | 2.5 | 4.11 | 5.02 | 5.56 |
| | G ₁₁ | | 3 | 3.98 | 4.71 | 4.78 |
| | G ₁₂ | | 3.5 | 3.55 | 3.98 | 4.10 |
| | | | | | | |
| GPC ₄ mix | G ₁₃ | 0.55 | 2 | 4.49 | 4.87 | 5.16 |
| | G ₁₄ | | 2.5 | 4.00 | 4.28 | 4.41 |
| | G ₁₅ | | 3 | 3.98 | 4.30 | 4.39 |
| | G ₁₆ | | 3.5 | 3.38 | 3.69 | 3.89 |
| | | | | | | |
| GPC ₅ mix | G ₁₇ | 0.6 | 2 | 3.97 | 5.13 | 5.17 |
| | G ₁₈ | | 2.5 | 4.21 | 4.68 | 4.75 |
| | G ₁₉ | | 3 | 3.11 | 4.55 | 4.60 |
| | G ₂₀ | | 3.5 | 3.19 | 3.66 | 3.91 |
| | | | | | | |

E. Cost analysis

The total cost of GGBS and Lye based geopolymer concrete is found to be 37.53% lower than ordinary geopolymer concrete and 49.07% higher than conventional concrete. Cost comparison of conventional concrete, GGBS and Lye based geopolymer concrete, ordinary geopolymer concrete is done as follows,

Table.4 Cost comparison

| Sl no. | Type of concrete | Cost per m ³ |
|--------|--------------------------------|-------------------------|
| 1 | Conventional concrete. | 4660.20 |
| 2 | Economized geopolymer concrete | 6946.98 |
| 3 | Ordinary geopolymer concrete. | 9554.18 |

F. Mix design calculation of Economized geopolymer concrete

In mix design of Economized geopolymer concrete absolute volume method is followed. The optimum mix design is obtained when alkaline activator to cementitious binder ratio is 0.5 and alkaline activator ratio is 2.5, this optimum mix exhibits good slump and compressive strength. The optimum mix design steps is as follows,

- Consider the unit weight of Economized geopolymer concrete same as conventional concrete i.e.; 2400 kg/m³.
- Total percentage of aggregates is taken as 70%, increase in total aggregates percentage decreases cementitious binder and vice-versa. As per trials done to improve the cohesiveness of mix it is taken as 70%.
- The product of total percentage of aggregates and unit weight gives total aggregates required.
 $0.7 \times 2400 = 1680 \text{ kg/m}^3$.
- The difference of unit weight and total aggregates gives cementitious binder; this cementitious binder is combination of alkaline activator and binder material.
 $2400 - 1680 = 720 \text{ kg/m}^3$.
- The total percentage of coarse aggregates and fine aggregates are decided as mainly depending on least void content. The product of percentage of coarse aggregates and total percentage of aggregates gives total weight of 12.5 mm coarse aggregates. The difference of total percentage of aggregates and total weight of coarse aggregates gives total weight of fine aggregates.

$$\text{Total weight of coarse aggregates} = 1680 \times (60 / 100) = 1008 \text{ kg/m}^3.$$

$$\text{Total weight of fine aggregates} = 1680 - 1008 = 672 \text{ kg/m}^3.$$

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- Ratio of alkaline activator to cementitious binder can be varied, as per trails conducted it was varied from 0.4, 0.45, 0.5, 0.55, 0.6 where 0.5 was optimum value achieved (it had good workability and compressive strength). As this ratio decreases the binder content gradually increases and workability improves by decreasing this ratio.

$$\frac{\text{Alkaline activator liquid (AA)}}{\text{Cementitious binder (CB)}} = 0.5$$

Let us consider cementitious binder (binder material) as 'x'.

$$AA = 0.5x.$$

But CB is combination of alkaline activator and binder material (from step 4).

$$AA + \text{binder material} = 720 \text{ kg/m}^3.$$

$$AA + x = 720 \text{ kg/m}^3.$$

$$0.5x + x = 720 \text{ kg/m}^3.$$

$$x = \text{binder material} = 480 \text{ kg/m}^3.$$

- Alkaline activator ratio is the ratio of sodium silicate to Lye. This ratio can also be varied, as per the trails conducted it was varied from 2, 2.5, 3, and 3.5 where 2.5 was optimum value achieved. By decreasing this ratio compressive strength gradually increases and by increasing this ratio workability gradually increases.

We know that, AA = 0.5x (from step 6).

$$\frac{\text{Sodium silicate}}{\text{Lye}} = AA = 0.5 \times 480 = 240 \text{ kg/m}^3.$$

$$\text{Lye} = 240 / (1 + 2.5) = 68.57 \text{ kg/m}^3.$$

Sodium silicate is achieved by subtracting AA and Lye.

$$240 - 68.57 = 171.43 \text{ kg/m}^3.$$

- To achieve total solids in Lye, Total solid test is carried out. As per this test conducted the total solids in Lye was found to be 2.296% and liquid content was 97.704%.

To find solid content in 68.57 kg/m³ Lye, it is multiplied with percentage of total solids in Lye.

$$\text{Solid content} = 68.57 \times (2.296 / 100) = 1.574 \text{ kg / m}^3.$$

Liquid content in 68.57 kg/m³ is obtained by subtracting it with solid content in 68.57kg/m³ of Lye.

$$\text{Liquid content} = 68.57 - 1.574 = 66.996 \text{ kg/m}^3.$$

- It is found that sodium silicate available commercially for industrial purpose has 55.9% total liquid and 44.1% total solids.

Liquid content in 171.43 kg/m³ of sodium silicate is obtained by multiplying it with percentage of total liquid.

$$\text{Liquid content} = 171 \times (55.9 / 100) = 95.83 \text{ kg/m}^3.$$

Solid content in 171.43 kg/m³ is obtained by subtracting it with liquid content in 171.43 kg/m³ of sodium silicate.

$$\text{Solid content} = 171.43 - 95.83 = 75.6 \text{ kg/m}^3.$$

- Water to geopolymer solid ratio is the ratio of liquid content in Lye and sodium silicate to binder material (cementitious binder) and solid content in Lye and sodium silicate.

$$\frac{\text{Water}}{\text{Geopolymer solids}} = \frac{95.83 + 66.996}{480 + 75.6 + 1.57} = 0.29 > 0.23$$

This ratio is freezed to 0.23 because for mixes having 0.6, 0.55, 0.5, 0.45 and 0.4 as alkaline activator liquid to cementitious binder ratio, it was seen that water to geopolymer solid ratio was not greater than 0.23 and for mixes with alkaline activator liquid to cementitious binder ratio = 0.4 and alkaline activator ratio of 3 and 3.5 had water to geopolymer solid ratio as 0.23. Hence, for mixes having water to geopolymer solid ratio up to 0.23, there is no need of adding extra water.

0.29 > 0.23, therefore extra addition of water is not required.

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Whereas for mixes having water to geopolymer solid ratio below 0.23 extra water should be added, extra water required is obtained by,

$$\text{Extra Water} = \left[\frac{\text{Water}}{\text{Geopolymersolids}} \times \text{geopolymer solids (binder material and solids present in Lye and sodium silicate)} \right] - [\text{geopolymer liquids (liquids present in Lye and sodium silicate)}].$$

Table5. Specifications of different Economized geopolymer concrete mixes.

| | Mix no. | Mix proportions | Water to geopolymer solids ratio | Density of specimen (kg/m ³) |
|----------------------|-----------------|-----------------|----------------------------------|--|
| GPC ₁ mix | G ₁ | 1:1.49:2.24 | 0.36 | 2390 |
| | G ₂ | 1:1.49:2.24 | 0.34 | 2450 |
| | G ₃ | 1:1.49:2.24 | 0.33 | 2360 |
| | G ₄ | 1:1.49:2.24 | 0.32 | 2440 |
| GPC ₂ mix | Mix no. | Mix proportions | Water to geopolymer solids ratio | Density of specimen (kg/m ³) |
| | G ₅ | 1:1.4:2.1 | 0.30 | 2330 |
| | G ₆ | 1:1.4:2.1 | 0.29 | 2470 |
| | G ₇ | 1:1.4:2.1 | 0.28 | 2410 |
| GPC ₃ mix | Mix no. | Mix proportions | Water to geopolymer solids ratio | Density of specimen (kg/m ³) |
| | G ₈ | 1:1.4:2.1 | 0.28 | 2360 |
| | G ₉ | 1:1.31:1.96 | 0.25 | 2460 |
| | G ₁₀ | 1:1.31:1.96 | 0.24 | 2370 |
| GPC ₄ mix | G ₁₁ | 1:1.31:1.96 | 0.23 | 2430 |
| | G ₁₂ | 1:1.31:1.96 | 0.23 | 2380 |
| | Mix no. | Mix proportions | Water to geopolymer solids ratio | Density of specimen (kg/m ³) |
| | G ₁₃ | 1:1.35:2.03 | 0.28 | 2410 |
| GPC ₅ mix | G ₁₄ | 1:1.35:2.03 | 0.27 | 2390 |
| | G ₁₅ | 1:1.35:2.03 | 0.26 | 2470 |
| | G ₁₆ | 1:1.35:2.03 | 0.25 | 2450 |
| | Mix no. | Mix proportions | Water to geopolymer solids ratio | Density of specimen (kg/m ³) |
| GPC ₅ mix | G ₁₇ | 1:1.45:2.17 | 0.33 | 2360 |
| | G ₁₈ | 1:1.45:2.17 | 0.32 | 2380 |
| | G ₁₉ | 1:1.45:2.17 | 0.31 | 2390 |
| | G ₂₀ | 1:1.45:2.17 | 0.30 | 2410 |

VIII. CONCLUSIONS

- Lye (potassium hydroxide lye) leached with waste wood ash is economical and effectively used as alkaline activator liquid to replace potassium hydroxide and sodium hydroxide which are locally available in market.
- For any geopolymer concrete mix the workability increases with increase in alkaline activator ratio.
- Compressive strength and split tensile strength increases with decrease in alkaline activator ratio.
- The total cost of Economized geopolymer concrete is found to be 37.53% lower than ordinary geopolymer concrete.
- The specimens were subjected to ambient curing rather than other accelerated curing to check the stability of GGBS and Lye based geopolymer concrete casted at in suite condition.

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- The 28 days strength shows a greater compressive strength when compared with conventional concrete. This gives a clear picture that this type of geopolymer concrete can be used as an alternative for conventional concrete.

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BIOGRAPHY



Nagaraj. V. K is a P.G. Student in the Department of Civil Engineering, Sri Venkateshwara College of Engineering, Bengaluru, Karnataka, India



Puttaswamy. B. K is an Assistant Professor in the Department of Civil Engineering, Sri Venkateshwara College of Engineering, Bengaluru, Karnataka, India