# STRENGTH AND DURABILITY STUDY OF GEOPOLYMER CONCRETE WITH 100% REPLACEMENT OF SAND USING COPPER SLAG

Sivaranjani.S., Sridhar. M.

**Abstract**— **One of the regularly used man made building material in the word is concrete. This concrete is comprising of sand and gravel. They are chemically inert and very hard. It is blended together by the addition of cement and water. Among these components, cement and sand are correlated with some issue which is considered as the drawback of the concrete. Requirements of the huge amount of energy, emission of carbon dioxide, increasing demand of river sand, overpriced of river sand are some of the problems have been confronted by construction industries during the use of conventional concrete. On the other hand, industrial by products are producing in huge amount which is not used properly by our country. Hence it is mandatory to find out the substitute solution to control these problems. Many alternatives have been founded by researchers. Geopolymer concrete is renowned among many alternatives. It consumes an alkaline solution along with industrial by-products and aggregates. The Alkaline solution is prepared by combining sodium hydroxide with sodium silicate. This alkaline solution reacts with silica and alumina present in the source material to produce an alumino silicate gel which is act as a bonding agent in geopolymer concrete. In this work, sand and cement were completely replaced by copper slag and fly ash respectively. Sodium silicate to sodium hydroxide ratio was taken as 2.0. Three different molarities i.e. 8M, 12M, and 16M were taken as test variables. Mechanical properties of this concrete were determined by conducting the tests. The compressive and split tensile strength of this geopolymer concrete was more or less similar or slightly greater than the normal geopolymer concrete. The maximum compressive strength obtained by copper slag based geopolymer concrete was 38 N/mm$^2$ and 4.77 N/mm$^2$ was the maximum tensile strength after 28 days of the oven curing. Production cost of copper slag-based GPC is less when compared to normal geopolymer concrete. From the durability aspects view it shows good resistance to chemicals attack.**

**Keywords – copper slag, admixture, durability, alkaline solution, steam curing, strength, molarity, workability, etc.**



## 1. INTRODUCTION

Concrete is a composite material used in the construction industry. It is composed of sand and gravel. This sand and gravels are blended together by the Cement Paste. Making of this cement comprises a large amount of natural resources such as lime stone, electricity, fossil fuel, and natural gas. Corban dioxide is released from the production process of cement into the atmosphere which leads to global warming. This Carbon dioxide is emitted due to the calcination of lime stone and combustion of fossil fuel. Production of 1 ton of cement produces 1 ton of carbon dioxide and it requires 4GJ energy for producing a ton of cement. The shortage of river sand is another problem in conventional concrete. Due to increasing the shortage, the price is also increased. Mining large quantities of river sand affect the ecology of river beds.

In addition, from industries like a thermal power plant, iron and steel making industries, copper factories, a large amount of waste products are generating. These wastes are simply disposed of in sea, pond or used in landfills. Hence, an alternative solution is required to overcome the above-mentioned problems. Researchers have conducted many types of researches to bring down the problem in concrete and to reuse or recycles the industrial wastes. Geopolymer concrete (GPC) is considered as the best alternative concrete to control these problems. It was introduced by the French professor Davidovits. GPC turns the industrial waste into eco-friendly concrete. Geopolymer concrete uses industrial waste or by products in the place of cement and fine aggregate. Any materials like fly ash, GGBS, copper slag, rice husk which is rich in silica and alumina can be used as source material. Alkaline solution is the most chief constituents of geopolymer concrete. This Alkaline activating solution is used to activate the silica and alumina present in source materials. Most commonly used alkaline solution is sodium hydroxide and sodium silicate. Potassium hydroxide can also be used but NaOH is preferred more. According the molarities sodium hydroxide solution is prepared one day before the casting due to the evolution of heat form the solution. At the day of casting sodium silicate solution is added to that sodium hydroxide solution. In GPC, Si and Al react with this alkaline solution and produce alumina silicate gel which acts as a bonding agent in geopolymer concrete.

## 2. LITERATURE REVIEW

The available published literature on Geopolymer technology is briefly reviewed. It involves research work on copper slag based geopolymer concrete, durability study, strength study, the effect on alkaline concentration, the influence of superplasticizer, workability properties etc.

**Burri yarshareddy. et.al. (2018).** Conducted a study on fly ash and GGBS based geopolymer concrete in which copper slag and vermiculite were used as fine aggregate. Fine aggregate was replaced at different levels (0%, 20%, and 40%). Compressive strength test and ultrasonic pulse velocity test were carried out after 7 and 14 days of ambient curing. A solution of sodium hydroxide and sodium silicate is used as an alkaline activator.

Conclusion drawn from this study is:

- The Strength of Geopolymer concrete decreased with increasing in vermiculate content.
- Strength increased by copper slag content.
- Polymerization reaction was increased by copper slag content. This polymerization densifies mix hence there was an increase in both ultra-pulse velocity and compressive strength.

**Mounika. B. et.al. (2017)**. Determined the mechanical properties of geopolymer concrete incorporating copper slag as fine aggregate. Due to the environmental impact cement was replaced by fly ash and GGBS. These binding materials are activated by Na2SiO3 and NaOH which is knowns as the alkaline solution. Copper slag was used in 5 different levels 0%, 10%, 20%, 30% and 40%. Compressive strength test, split tensile strength test and modulus of elasticity tests was carried out at the age of 7,28 and 90 days.

Following conclusions were drawn from the study:

- Compressive strength was increasing from 0% to 40% of replacement level. This is due to fine materials of copper slag, fill the voids. Hence, strength was increased which in turn increased the other engineering properties.
- Split tensile strength and modulus of elasticity also increased due to the addition of copper slag.

Results obtained from the study are:

- Use of copper slag reduce the environmental problem and reduce the production cost of concrete.
- In GPC 2, 17.5% of compressive strength, 13.94% of split tensile strength and 22.72% flexural strength increased when compared to GPC1
- It is suitable to achieve high strength concrete.

**Mahendran Kandhasamy. et.al. (2015).** Researched the application of copper slag in geopolymer concrete as fine aggregate. Fine aggregate was replaced by copper slag in five different proportion of 10%, 20%, 30%, 40%, and 50%. Sodium hydroxide and sodium silicate were used as an alkaline solution. Sodium hydroxide to sodium silicate ratio was 2.5. Curing temperature greatly influence the strength of the concrete. In this study, geopolymer concrete was cured at $50^0$c for 24hrs to 48hrs and also left to cure in the ambient condition.

Following observations were drawn from the study:

- Hot air oven cured specimens showed good engineering properties when compared to the ambient cured specimen.
- The Strength of the concrete was directly proportional to the copper slag content.
- Geopolymer concrete showed maximum compressive and tensile strength which was cured at $60^0$C when compared to ambient cured concrete.

**Mohammed Asif et.al. (2018).** Explored the properties of concrete in which copper slag was used. In this study fine aggregate was replaced in four different proportion i.e. 0%, 20%, 40%, 60%, and 80% by copper slag. M 25 grade concrete was taken and the mechanical properties were assessed by conducting a series of tests on the 28th day of curing.

Following were the results achieved from the study:

- Maximum compressive strength, flexural strength, and split tensile strength were attained at 40% replacement of copper slag. Hence this is the optimum proportion.
- Density was increased.

**Patil.M.V.(2015).** Analyzed the influence and properties of copper slag-based concrete. Here, copper slag was used as a fine aggregate in the production of concrete. The Fine aggregate replacement was done from 0% to 100% in concrete by copper slag and the tests were conducted for each proportion. Mix design for M 30 was done. Tests were conducted for normal concrete also and the results were compared.

Conclusions of this study are:

- Copper slag increased the workability of concrete.
- Copper slag base concrete obtained good results in strength up to 80% replacement than the normal concrete.
- Maximum compressive strength was obtained at 20% replacement
- Flexure strength was more than the normal concrete for all percentage of replacement and maximum flexure strength was at 30% replacement.

- The Density of concrete was also increased by copper slag. 7% increased at 100% replacement.
- It also reduces the overall production cost of concrete.

**Salmabanu luhra.et.al. (2015).** Determined the durability characteristics of geopolymer concrete by conducting the various test on both geopolymer concrete and control concrete specimens and the results were compared. Because of cement production contribute to 7% of the global carbon dioxide emission it was replaced by fly ash. Tests like Sulphate resistance test, acid resistance test, chloride resistance test, and water absorption test were conducted. Chemicals used for these studies were sodium chloride, sulphuric acid, and sodium sulphate.

Results attained from this study are:

- The test results showed that geopolymer concrete has excellent chloride and sulphate resistance.
- Sulphuric acid damaged the surface of geopolymer concrete specimens and compressive strength was also decreased. However, sulphuric acid resistance is better than the normal concrete.
- Fly ash is finer than OPC. So, the porosity of geopolymer concrete is less which results in less absorption of water.

**Brahammaji.et.al. (2015).** Presented the experimental work on the behavior of fly ash based geopolymer concrete in a chemical atmosphere. Geopolymer concrete delivered by the reaction between source materials which are rich in silica and alumina and alkaline solution. HCl, $MgSO_4$, and $H_2SO_4$ were the three types of chemicals used in this study. Specimens were immersed in chemicals and tested at 7, 14, and 28 days for each chemical and the results were compared with conventional concrete.

Outcomes from this study are:

- Percentage of loss of compressive strength is less than the conventional concrete at all the ages of acid exposure.
- The Maximum loss of compressive strength occurred in $H_2SO_4$ immersion.
- Weight loss percentage was more in conventional concrete for all three types of acid used in this study.
- Geopolymer concrete was less sensitives to $MgSO_4$. Because it showed more percentage of compressive strength loss when compared to conventional concrete.

**Bapugouda patil.et.al. (2015).** Analyzed the durability properties of geopolymer concrete in which pond ash and M sand were used as a fine aggregate due to the shortage and overpriced of the river sand. Many ecological issues like calcination of limestone and ignition of fossil fuel release 1-ton $CO_2$ for every 1 ton of OPC production. Due to these reasons, cement was replaced by fly ash and GGBS. 14M concentration of NaOH was used along with $Na_2SiO_3$ as an alkaline solution. 100mm cubes were casted to test the strength and durability properties. Acid, sulphate chloride and fire resistance tests were conducted to determine the durability of geopolymer concrete and the results were compared with normal strength concrete.

Following was the finding of this study:

- Very minute changes were observed in geopolymer concrete which was immersed in HCl.
- Geopolymer concrete immersed in MgSO4 and NaCl gained more weight hence the strength of specimens increased.
- In case of fire resistance, geopolymer concrete was superior to normal strength concrete.

**Sandeep L. hake. et.al. (2016).** Studied the effect of molarity on geopolymer concrete made by using fly ash. An Alkaline liquid used in this study was sodium hydroxide (NaOH) and sodium silicate (Na2SiO3). Role of alkaline liquid is to activate the Si and Al present in the fly ash. Different geopolymer concrete mixes were prepared for various concentration of NaOH such as 8M, 10M, 12M, 14M, 16M, and 18M. Three cubes were prepared for each molarity and cured in an oven at $80^0$c. These cured specimens were tested at the age of 7 days and 28 days.

Conclusions drawn from this study are:

- Molarity of NaOH is directly proportional to the compressive strength of geopolymer concrete.
- The Minimum result was found in 8M geopolymer concrete mix.

**Robina kouser tabassum. et.al. (2015)**. Presented an extensive study on the impact of sodium hydroxide concentration on various properties of geopolymer concrete. Combination of NaOH and $Na_2SiO_3$ were used as an alkaline solution. NaOH with different molarities i.e. 8M, 12M and 16M (mix1, mix2, and mix3) were chosen. After 7 days and 28days of oven curing the test such as slump test, compressive strength test, split tensile strength test and water absorption test was conducted to determine the changes occurred due to different molarities of NaOH. A Ratio between sodium silicate and sodium hydroxide was 2.5 and it was kept constant for all the 3 mixes. Specimens were cured in an oven at $65^0$c.

Following were the conclusions drawn from the study:

- The test results stated that the slump value for mix1, mix2, and mix3 were 35mm, 100mm, and 145mm respectively.
- Maximum compressive strength was founded in mix3 in which 16M of NaOH was used.
- Both tensile strength and flexural strength also increased with increase in molarities.

- Water absorption was increased from 8M to 16M of NaOH. Maximum water absorption was found in mix 3.

**Girawale (2015).** Studied the effects on geopolymer concrete due to an alkaline solution. Geopolymer concrete greatly reduces the $CO_2$ emission. The main objective of this study was to determine the properties of GPC which varies according to various $Na_2SiO_3$/NaOH ratios and different molarities of NaOH. The curing temperature of $80^0$c was kept constant, it was kept in an oven for 24hrs. Compressive strength test, flexural strength test, and split tensile strength test were conducted and it was compared with normal concrete. The Ratio between $Na_2SiO_3$/NaOH was 2.5. 3 and 3.5. Different molarities (12M, 14M, 16M) were adopted for each $Na_2SiO_3$/NaOH ratio.

Conclusions drawn from this study are:

- Geopolymer concrete gave better a result than the normal concrete.
- Molarities (12M, 14M, 10M) increased the strength of the concrete.
- The strength of the geopolymer concrete was also increased when $Na_2SiO_3$/NaOH ratio increased (2.5, 3.0, 3.5)
- High compressive strength gained in 24hrs, hence geopolymer concrete can accelerate the speed of the construction.

**Mithanthaya I.R. et.al. (2017).** Analyzed the influence of superplasticizer on the properties of geopolymer concrete using industrial waste. Authors attempted to produce the geopolymer concrete using industrial waste material like fly ash, GGBS, and glass powder. Two phases of mix design were carried at 1st phase involved the preparation of geopolymer concrete using fly ash and glass powder. Glass powder was added in different percentage 0%, 10%, 15% and 20% with and without of superplasticizer. Optimum dosage of glass powder was obtained from the result. 2nd phase involved the preparation of geopolymer concrete using optimum dosage of glass powder and GGBS which replaced the fly ash in the percentage of 0%, 5%, 10% 15% and 20% with and without superplasticizer. Compressive and tensile strength test were performed on specimens.

Conclusion drawn from the study are:

- Superplasticizer increased the strength both in phase 1 and phase2.
- Optimum dosage of glass powder was 15% by weight of fly ash.
- Optimum use of GGBS was 15% of fly ash.
- Mix involved in phase 2 attained higher strength than phase 1.

**Triwalan.et.al. (2016).** Have tried to increase the workability of geopolymer concrete by adding superplasticizer. Here, geopolymer concrete was made by using fly ash and alkaline activator in the ratio of 74%:26%. The alkaline solution was Sodium hydroxide (12M) and sodium silicate. The percentage of naphthalene-based superplasticizer used to prepare geopolymer concrete varied from 1.5 to 3 % of fly ash mass. 1.5 to 3 were the ratio of Na2SiO3/NaOH. Tests conducted on concrete were Compressive strength test and density test.

Following are the inference drawn from the study:

- Outcomes of the tests showed that the highest compressive strength was achieved by the mix which involved 1.5% of superplasticizer.
- For tensile strength, optimum percentage of superplasticizer was 1.5 and optimum Na2SiO3/NaOH ratio was 2.5.
- Maximum compressive strength was achieved in the proportion of Na2SiO3/NaOH =2.

**Siva Konda Reddy. B et.al. (2010)** conducted a study on the strength and workability of geopolymer concrete. Low calcium which is mostly composed of Si and Al was used to prepare gpc.it was activated by alkaline solution (NaOH + Na2SiO3). NaOH added in 4 different concentration i.e. 10M,12M,14M and 16M. 1.5% of superplasticizer to fly ash mass was added to increase the workability slump cone, vee bee and compressive strength test was carried out to determine the workability and compressive strength for each geopolymer concrete mix prepared by using 4 different molarities. The specimens were cured and oven cured at $60^0$c.

Following were the Inference drawn from this study:

- There was no much impact on compressive strength for the addition of 1.5% of superplasticizer but it increased the workability.
- Workability decreased with increase in molarity which results in high compressive strength.
- High concentration of molarity results in high compressive strength.

**Shaik usman and Rajesh kumar.M (2017).** Investigated the strength of geopolymer concrete using fly ash and quarry dust. Here, cement is fully replaced by fly ash and fine aggregate is replaced with quarry dust. Three different molarities i.e. 8M, 10M, and 12M of NaOH were taken. Different types of mixes were prepared, GPC1, GPC2, GPC3 and mix for conventional concrete. Compressive strength and split tensile strength were tested after 7, 14, and 28 days curing.

Following conclusions were obtained from this study:

- Environmental pollution can be reduced by using the industrial by product

- The result showed that the strength of geopolymer concrete increased with increase in molarity of sodium hydroxide.
- Geopolymer concrete gave a better result when compared to conventional concrete.
- Among 3 different geopolymer concrete mix (GPC1, GPC2, GPC3) the mix GPC3 gave higher strength due to high molarity of NaOH.

**Gawrav nagalia.et.al. (2016).** Examined the changes occurred in compressive strength and microstructure of geopolymer concrete due to alkaline hydroxide and its concentration. Sodium hydroxide (NaOH), potassium hydroxide (KOH), barium hydroxide ($Ba(OH)_2$) and lithium hydroxide (LiOH) are the alkaline solution used to prepare geopolymer concrete. Mechanical properties are greatly influenced by curing condition and curing time. Hence, different curing condition and curing time were adopted. Molarities of NaOH were 8M, 12M, and 14M.

Results obtained from this study are:

- Among different alkaline hydroxide, NaOH gave high strength.
- A mixture of alkaline hydroxide didn't give any benefits.
- Higher molarity (14M) of NaOH improved the strength when compared to 8M and 12M.
- High temperature and longer curing period improved the compressive strength.

**Pattanapong topark-ngram.et.al. (2014).** Investigated the setting time, strength and bond strength of high calcium fly ash geopolymer concrete. The alkaline solution was sodium hydroxide and sodium silicate. Different concentration of sodium hydroxide 10M, 15M, 20M, and sodium hydroxide to sodium silicate ratio (S: H) of 1.0 and 2.0 were used in every mix. Two curing regimes room temperature curing and heat curing were adopted. The temperature of the heat curing was $60^0c \pm 2^0c$ for 24hrs.compresive strength test, split tensile strength test and bond strength test was conducted and the results were compared with normal concrete.

Following observations were drawn from the study:

- Compressive strength was high in oven curing than in room temperature curing.
- Geopolymer concrete showed higher modulus of elasticity value was obtained for the geopolymer concrete which was prepared with S: H ratio of 1.
- The maximum compressive strength of 54.4Mpa was obtained for 15M NaOH.
- Bond strength of geopolymer concrete was higher than the normal concrete.

**Djcvantore hardjito.et.al. (2004).** Looked into the factors that affect the compressive strength of geopolymer concrete which was made by using fly ash. Age of concrete, curing time, curing temperature, a quantity of superplasticizer, rest period and water content of the mix were the test variables.

Results drawn from this study are:

- Age of the concrete didn't affect the compressive strength.
- High compressive strength was attained when the specimens were cured for longer curing time.
- Superplasticizer improves the workability without any changes in compressive strength up to 2% by mass of fly ash.
- Small changes were observed between the specimens cured immediately and cured for 60 mins after casting.
- Compressive strength was increased up to $75^0c$.

**Sonal P. Thakkar. et.al. (2014).** Probed the geopolymer concert using different source materials such as fly ash and GGBS. To reduce the $CO_2$ emission and to use the waste materials the authors tried to use fly ash and GGBS as a replacement material for cement in GPC at ambient temperature. Generally, geopolymer concrete requires heat treatment which is considered as a drawback. A Comparison was done between ambient and oven curing. Different mix proportion of fly ash and GGBS was carried out to produce geopolymer concrete. Mix A in which fly ash/ slag ratio was 90/10, mix B - 70/30 and mix C - 50/50. The specimens were casted and kept for 1 day as rest period and then kept in an oven at $90^0c$. for 24hrs and 48hrs.

Following were the inference drawn from this study:

- Oven cured geopolymer concrete gave higher strength than ambient cured geopolymer concrete.
- Higher concentration of GGBS achieved higher compressive strength.
- Among 3 mixes, Mix C (50:50) was considered as an optimum dosage.

## 3. METHODOLOGY AND MATERIALS TESTING

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Materials collection and testing
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Design of mix proportions
↓
Testing on fresh geopolymer concrete
↓
Casting of specimens
↓
Curing of specimens
↓
Testing on hardened geopolymer concrete
↓
Results and Conclusion

## MATERIALS

Alkaline solution – sodium hydroxide flakes and sodium silicate liquid.

Source materials – fly ash, copper slag, coarse aggregate.

### 3.1 Fly ash

About 70 – 75% of total power generated in India is produced by coal-based thermal power plant. These thermal power plants produce a large amount of fly ash. During the process of power generation pulverized coal is burned from where the fly ash is obtained as by product. class F and class C are the type of fly ash based on the coal used .class f fly ash have less calcium content when compare to class c fly ash.

**TABLE 1 PHYSICAL PROPERTIES OF FLY ASH**

| Physical properties | Results | Range |
|---|---|---|
| Specific gravity | 2.6 | 2.1 - 3 |
| Fineness modulus | 10% | ≤ 10 |
| pH | 8.49 | 6 - 10 |
| Shape | Spherical | |

**TABLE 2 CHEMICAL PROPERTIES OF FLY ASH**

| Chemical components | % of chemical components |
|---|---|
| $SiO_2$ | 54.90 |
| $Al_2O_3$ | 25.80 |
| $Fe_2O_3$ | 6.90 |
| CaO | 6.75 |
| MgO | 1.80 |
| $SO_3$ | 0.60 |



### 3.2 Copper slag (CS)

Copper slag is the byproduct of copper extraction by the process of smelting. Copper slag is glassy, black and have shinning appearance. 3 tons of copper slag is generated for every one-ton production of copper. It can be used in conventional concrete as a substitute substance for aggregate upto 60%. It can also be used in GPC. Geopolymer concrete using this copper slag is workable without adding superplasticizers due the low water absorption property of the copper slag. Using copper slag in concrete greatly reduce the disposal problem and reduce the cost of concrete production.

**TABLE 3 PHYSICAL PROPERTIES OF COPPER SLAG**

| Physical properties | Results | Range |
|---|---|---|
| Specific gravity | 3.8 | 3 - 4 |
| Water absorption | 0.4% | 0.3 – 0.6 |
| Fineness modulus | 3.32 | 3 - 5 |

**TABLE 4 CHEMICAL PROPERTIES OF COPPER SLAG**

| Chemical components | % of chemical components |
|---|---|
| $SiO_2$ | 25.84 |
| $Fe_2O_3$ | 68.29 |
| $Al_2O_3$ | 0.22 |
| CaO | 0.15 |
| $Na_2O$ | 0.58 |
| $K_2O$ | 0.23 |
| $TiO_2$ | 0.41 |
| $SO_3$ | 0.11 |
| CuO | 1.20 |

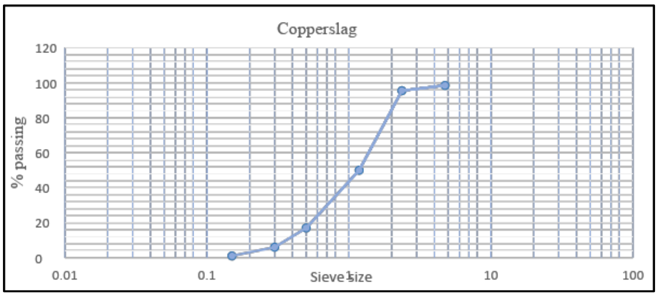


**Fig.1** **Grain size distribution curve for copper slag**

### 3.3 Coarse aggregate

Coarse aggregate occupies 60 to 75 % of total volume of concrete. It is inert material. Aggregate size higher than 4.75 mm sieve are knowns as coarse aggregate. Aggregates are generally available from both natural and artificial source. Production process of aggregate include extraction, crushing, screening, handing, washing and storing specification for aggregate is given in IS: 383

TABLE 5 PHYSICAL PROPERTIES OF COPPER SLAG

| Physical properties | Range | Results |
|---|---|---|
| Impact value | 10 – 20 % | 12.5 % |
| Water absorption | 0.5 - 1% | 0.5% |
| Fineness modulus | 6.5 - 8 | 7.14 |

### 3.4 Sodium hydroxide flakes (NaOH)

Sodium hydroxide is also known as caustic soda. It generally available in 2 different form i.e. flakes and pellets. In this study it was taken in the flakes form. In geopolymer concrete Sodium hydroxide plays a vital role. It acts as an activating agent in geopolymer concrete. sodium hydroxide solution was prepared by dissolving it in 1 liter of water according to the molarities. This molarities greatly influences the workability and strength of geopolymer concrete.

TABLE 6 PHYSICAL PROPERTIES SODIU HYDROXIDE

| Properties | Values |
|---|---|
| State | Solid to liquid |
| Molecular weight | 12206 g/mol |
| Density | 2.4 g/cm$^3$ |
| Melting point | 108°c |
| Boiling point | 102°c |
| Specific gravity | 1.6 |

TABLE 7 CHEMICAL PROPERTIES SODIUM HYDROXIDE

| Chemical components | % of chemical components |
|---|---|
| $Na_2CO_3$ | 2% |
| Cl | 0.01 % |
| $SO_2$ | 0.05 % |
| Pb | 0.01 % |
| Fe | 0.01 % |
| K | 0.1 % |
| Zn | 0.02% |

### 3.5 Sodium silicate liquid $Na_2SiO_3$

Sodium silicate is also known as soluble glass or water glass. It can be used as an accelerator for concrete. It is the major component of geopolymer concrete mix. Sodium silicate is always used in combination with sodium hydroxide to activate geopolymeric source materials.

TABLE 8 PHYSICAL PROPERTIES OF SIDIUM SILICATE

| Properties | Values |
|---|---|
| State | Solid - liquid |
| Molecular weight | 122.06 g/mol |
| Density | 2.4 g/cm$^3$ |
| Melting point | 1088°c |
| Boiling point | 102°C |
| Specific gravity | 1.6 |

TABLE 9 CHEMICAL PROPERTIES SODIUM SILICATE

| Chemical components | % of chemical components |
|---|---|
| $Na_2O$ | 15.9 % |
| $SiO_2$ | 31.4 % |
| $H_2O$ | 52.7 % |



## 4. MIX DESIGN

### Mix proportioning of geopolymer concrete of m 30 grade

**Step 1: Unit weight of geopolymer concrete**

Unit weight of geopolymer concrete = 2400 kg/m$^3$

**Step 2: Calculation of quantity of fine and coarse aggregate:**

Aggregates = 77 % of unit weight = 1848 kg/m$^3$

Coarse aggregate = 70% of 184 = 1294 kg/m$^3$

Fine aggregate = 30% of 1848 = 554 kg/m$^3$

**Step 3: Calculation of quantity of flyash content**

Mass of flyash and alkaline liquid = 2400 - 1848

Flyash (x) + Alkaline liquid (y) = 552 kg/m$^3$

Alkaline liquid (y)/Flyash (x) = 0.46

Alkaline liquid (y) = 0.46x

x + 0.46x = 552

Flyash (x) = 552/1.46

Therefore **Flyash** **= 378 kg/m$^3$**

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**Step 4: Calculation of quantity of alkaline liquid**

| | |
|---|---|
| Flyash (x) + Alkaline liquid (y) | = 552 kg/m³ |
| 378 + y | = 552 |
| Therefore, **alkaline liquid** | **= 174 kg/m³** |
| Alkaline liquid (NaOH + $Na_2SiO_3$) | = 174 kg/m³ |
| $Na_2SiO_3$(b)/NaOH (a) | = 2.5 |
| $Na_2SiO_3$ (b) | = 2.5a |
| a + 2.5b | = 174 |
| NaOH (a) | = 174/3.5 |
| Therefore, **Sodium hydroxide** | **= 49.7 kg/m³** |
| **Sodium silicate** | **= 124 kg/m³** |

**Step 4: Mix proportion**

| | |
|---|---|
| Fine aggregate (copper slag) | = 554 kg/m³ |
| Coarse aggregate | = 1294 kg/m³ |
| Flyash | = 378 kg/m³ |
| Sodium hydroxide (NaOH) | = 49.7 kg/m³ |
| Sodium silicate ($Na_2SiO_3$) | = 124 kg/m³ |

## 5. FRESH AND HARDENED GEOPOLYMER CONCRETE TEST

### 5.1 Mixing, casting and curing of geopolymer concrete

GPC consumes alkaline solution, industrials by products and aggregates. This alkaline solution was prepared by combining sodium hydroxide and sodium silicate. According to the molarities Sodium hydroxide was prepared one day before the casting by dissolving the flakes in water. For 8M- 26.23% of flakes was added in 1 liter of water. Same way for 12M-36.9% and for 16M-44.44% of flakes were added to the one liter of water. On that day of casting sodium hydroxide solution was mixed with sodium silicate liquid. After this dry mix was done. Fly ash, copper slag, and coarse aggregated were mixed for about 2 to 3 minutes. Then alkaline solution was added to the dry mix and the mixing was continued for few minutes. After the proper mixing it was filled in the mould in 3 layers. Each layer compacted by tamping it for 25 times using standard tamping rod. It is then left for one day as rest period. Geopolymer concrete required heat for polymerization reaction. So generally, steam curing or oven curing is preferred. And certain temperature should be maintained for 24hrs, 48hrs or 96 hrs. In this study, specimens were placed in oven at 60$^0$c for 24 hrs. After the oven curing specimens were kept in ambient condition till the date of test.




### 5.2 Fresh Geopolymer Concrete Test

#### Workability Test

Workability is a property of concrete which represent the ease and homogeneity of mix. Geopolymer concrete is less workable when compare to the conventional concrete. so, workability is increased by adding the superplasticizer to the geopolymer concrete mix. But in case of copper slag based geopolymer concrete workability is more than the normal geopolymer concrete. Because copper has poor water absorption property. Workability can be determined by conducting a slump cone test which is shown in Table 10 and Table 11. Even though the slump value of normal GPC was above 100mm the mix was very stiff. Workability of GPC decreased with increase in molarities of NaOH.


TABLE 10 WORKABILITY OF NORMAL GPC

| Molarity | Workability (mm) |
|---|---|
| 8M | 115 |
| 12M | 110 |
| 16M | 90 |

TABLE 11 WORKABILITY OF CS BASED GPC

| Molarity | Workability (mm) |
|---|---|
| 8M | 150 |
| 12M | 140 |
| 16M | 135 |

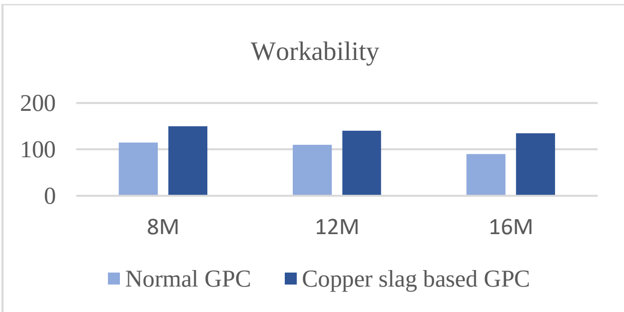


**Fig. 2 workability of normal and copper slag-based GPC**

### 5.3 Hardened Geopolymer Concrete Test

#### 5.3.1 Compressive Strength Test

Compressive strength is the capability of the concrete to withstand the load without any deflection It is determined by conducting a compressive strength test on concrete cube specimen. Size of the specimen was 150* 1051*150. In geopolymer concrete compressive strength is greatly affected by the rest period, curing temperature, curing methods, addition of admixture, concentration of alkaline solution etc. In geopolymer concrete, as the concentration of sodium hydroxide increased the strength will also increase. In this study compressive strength as determined for three molarities (8M, 12M, and 16M) for both normal and copper slag-based GPC which is shown in Table 12 and Table 13. Graphical comparison between slump values of normal GPC and copper slag-based GPC is shown in figure 3, figure 4, and figure 5.

TABLE 12 COMPRESSIVE STRENGTH OF NORMAL GPC

| Molarity | Compressive Strength N/mm² | | |
|---|---|---|---|
| | 7 days | 14 days | 28 days |
| 8M | 17.3 | 26.6 | 29.5 |
| 12M | 18.2 | 27.1 | 30.8 |
| 16M | 19.5 | 28.2 | 31.1 |

TABLE 13 COMPRESSIVE STRENGTH OF CS BASED GPC

| Molarity | Compressive Strength N/mm² | | |
|---|---|---|---|
| | 7 days | 14 days | 7 days |
| 8M | 21.7 | 27.5 | 33.3 |
| 12M | 23.5 | 29.1 | 36 |
| 16M | 27.37 | 30.2 | 38.08 |



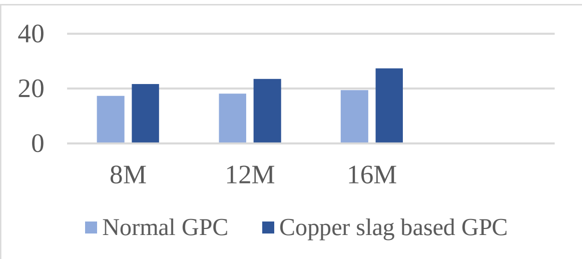


Fig.3 Compressive strength at the age of 7 days

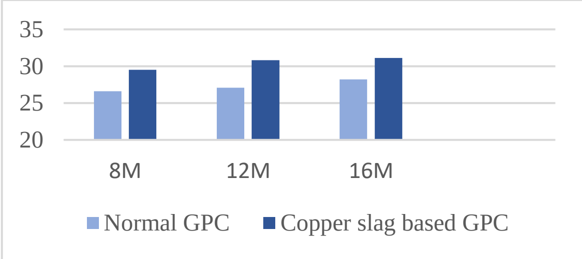


Fig.4 Compressive strength at the age of 14 days

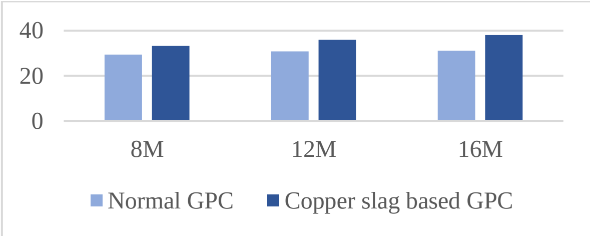


Fig.5 Compressive strength at the age of 28 days

#### 5.3.2 Tensile Strength Test

Tensile strength is the ability of concrete to withstand the pulling force without break. Concrete structures are highly susceptible to tensile cracking. Tensile strength is determined by conducting a splitting tensile strength test on concrete cylinder which is shown in Table 14 and Table 15. Size of the specimen is 150mm*300mm. Graphical representation of tensile values are given in Figure 6, Figure 7 and Figure 8.

**Split tensile strength = 2P / 3.14*D*L**

TABLE 14 SPLIT TENSILE STRENGTH OF NORMAL GPC

| Molarity | Tensile Strength N/mm² | | |
|---|---|---|---|
| | 7 days | 14 days | 7 days |
| 8M | 1.47 | 1.59 | 1.65 |
| 12M | 1.90 | 2.22 | 2.32 |
| 16M | 2.54 | 2.6 | 2.64 |

TABLE 15 SPLIT TENSILE STRENGTH OF CS BASED GPC

| Molarity | Tensile Strength N/mm² | | |
|---|---|---|---|
| | 7 days | 14 days | 7 days |
| 8M | 3.3 | 3.50 | 3.56 |
| 12M | 3.6 | 3.72 | 4.04 |
| 16M | 4.2 | 4.6 N | 4.77 |

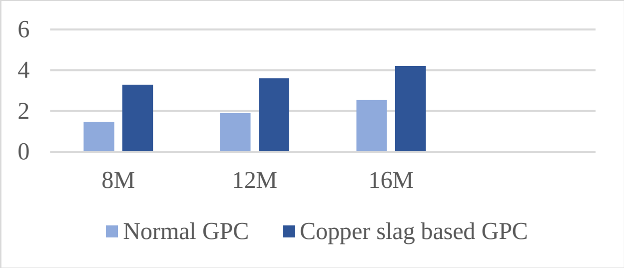


**Fig.6 Tensile strength at the age of 7 day**

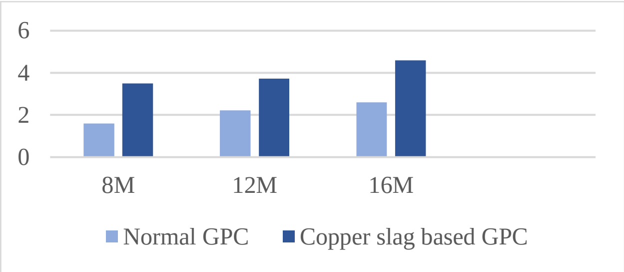


**Fig.7 Tensile strength at the age of 14 days**

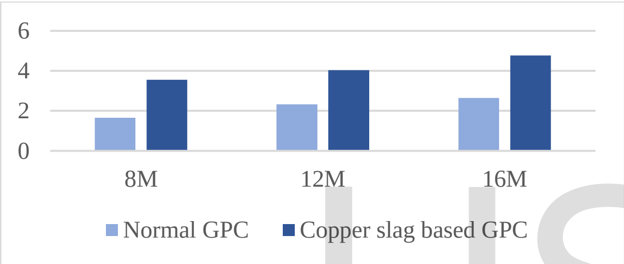


**Fig.8 Tensile strength at the age of 28 days**

### 5.4 Durability of Geopolymer Concrete

Durability is defined as the ability of concrete to resist weathering action, chemical attack, and abrasion without any defect to the structure for a long period of life. It is also referred as trouble-free performance. Durability involves the interaction with the environment in which the concrete structure is located. Improper construction, poor material, improper mix design, permeability of material, cover thickness are the factors which affect the life if the structure. Sulphate resistance test, chloride resistance test, acid resistance test, carbonation test are some of the durability test to determine the durability properties of geopolymer concrete.

### 5.4.1 Sulphate Resistance Test

Sulphates are present in groundwater, soil or industrial waste water and it will enter into the concrete structure through the pores present in the concrete and affect the properties of the concrete structure. This test is conducted to determine effect of sulphate on concrete. Concrete specimens were allowed to immersed in sulphate solution for a period of 30days and 40days. To prepare sodium sulphate solution 5% of sodium sulphate ($Na_2SO_4$) was mixed with water. For each 100gm of solution 95gm of water and 5 gram of sodium sulphate powder is added. After the sulphate exposure, the specimens were tested in the compressive tensing machine and the results were compared with the compressive strength before the sulphate exposure. Refer the Table 16 and Table 17.

**TABLE 16 SULPHATE RESISTANCE TEST ON NORMAL GPC**

| Molarity | Compressive strength before sulphate exposure N/mm² | Compressive strength after sulphate exposure | |
|---|---|---|---|
| | | 30 days | 40 days |
| 8M | 29.5 | 27.34 | 26 |
| 12M | 30.8 | 28 | 26.2 |
| 16M | 31.1 | 29.6 | 28.4 |

**TABLE 17 SULPHATE RESISTANCE TEST ON CS BASED GPC**

| Molarity | Compressive strength before sulphate exposure N/mm² | Compressive strength after sulphate exposure | |
|---|---|---|---|
| | | 30 days | 40 days |
| 8M | 33.3 | 31.3 | 26.5 |
| 12M | 36 | 35.2 | 27.1 |
| 16M | 38.08 | 37.2 | 29 |



### 5.4.2 Chloride Resistance Test

This test was performed to study the chloride resistance property of geopolymer concrete by exposing the concrete specimens to sodium chloride solution. Sodium chloride solution with 3 % concentration was prepared by mixing 3 gm of sodium chloride powder with 97 gm of water for every 100 gm of solution. Specimens were immersed in solution for 30 days and 40 days. After the period of exposure compressive strength was calculated. Strength loss was less when compared to other chemical exposure. Table 18 shows the chloride resistance test on normal GPC and Table 19 shows the chloride resistance test on copper slag-based GPC.

**TABLE 18 CHLORIDE RESISTANCE TEST ON NORMAL GPC**

| Molarity | Compressive strength before chloride exposure N/mm² | Compressive strength after chloride exposure | |
|---|---|---|---|
| | | 30 days N/mm² | 40 days N/mm² |
| 8M | 29.5 | 28 | 26 |
| 12M | 30.8 | 28 | 27.53 |
| 16M | 31.1 | 29.7 | 28 |

**TABLE 19 CHLORIDE RESISTANCE TEST ON CS BASED GPC**

| molarity | Compressive strength before chloride exposure $N/mm^2$ | Compressive strength after chloride exposure | |
|---|---|---|---|
| | | 30 days $N/mm^2$ | 40 days $N/mm^2$ |
| 8M | 33.3 | 32.2 | 30 |
| 12M | 36 | 35.16 | 34.12 |
| 16M | 38.08 | 37 | 36.46 |

### 5.4.3 Acid Resistance Test

This test determines the acid resistance property of geopolymer concrete by exposing the concrete specimens to the sulphuric acid(H2SO4) Solution. The concentration of sulphuric acid in sulphuric acid solution was 5%. For every 100gm of solution 5 gm of sulphuric acid and 95 gm of water was taken. For complete immersion of cube specimens in solution, it required more or less 9 liters of water. After the exposure, the cubes were tested. Compressive strength after the acid exposure was less when compared to the other chemical exposure. Table 20 and Table 21 represents the acid test on normal and copper slag based geopolymer concrete respectively

**TABLE 20 ACID RESISTANCE TEST ON NORMAL CONCRETE**

| Molarity | Compressive strength before acid exposure $N/mm^2$ | Compressive strength after acid exposure | |
|---|---|---|---|
| | | 30 days $N/mm^2$ | 40 days $N/mm^2$ |
| 8M | 29.5 | 24.34 | 22 |
| 12M | 30.8 | 26 | 22.2 |
| 16M | 31.1 | 28.6 | 26.4 |

**TABLE 21 ACID RESISTANCE TEST CS BASED GPC**

| Molarity | Compressive strength before acid exposure $N/mm^2$ | Compressive strength after acid exposure | |
|---|---|---|---|
| | | 30 days $N/mm^2$ | 40 days $N/mm^2$ |
| 8M | 33.3 | 29.3 | 24.5 |
| 12M | 36 | 31.2 | 27.1 |
| 16M | 38.08 | 33.81 | 26.3 |

### 5.4.4 CARBONATION TEST

when the moist concrete structure is exposed to the atmosphere, the pH of the concrete is reduced by reacting with the carbon dioxide present in the atmosphere. Carbon dioxide penetrates into the concrete and carbonated the concrete and reduce the alkalinity of concrete. depending upon the alkalinity content, pH of pore water in concrete is between 12.5 to 13.5. High alkalinity will protect the reinforcement corrosion by creating a passivating layer around the steel reinforcement. When the pH is below 10, reinforcement corrosion will occur which leads to the formation of cracks and deterioration take place. Carbonation test is conducted by spraying the phenolphthalein indicator on the surface of the concrete specimens. The Appearance of pink color indicated that the concrete is in good condition which is shown in figure 4.14. This test was conducted after the 14 days of curing.

## CONCLUSION

- Geopolymer concrete is a best alternative for conventional concrete to mitigate all the environmental issues.
- Production cost of geopolymer concrete was less when compared to conventional concrete because of the elimination of sand and addition of industrial by products.
- Mechanical properties of copper slag-based GPC was more than the normal GPC and the strength was directly proportional to molarities of sodium hydroxide.
- GPC mix is the stiff mix. It has less workability compared to conventional concrete. But in case of copper slag and fly ash-based GPC the workability was high. Because copper slag has poor water absorption property and particle size of fly ash was spherical which will reduce the ball bearing effect.
- Hence, copper slag-based GPC doesn't require any addition of superplasticizer which will further reduce the cost of GPC and it doesn't require extra water also.
- Optimum curing temperature for curing the geopolymer concrete was $60^0$c for 24 hrs. For curing the geopolymer concrete the specimens were kept inside the oven along with the mould. Because copper slag based geopolymer concrete require 2 to 4 days of rest period.
- Maximum compressive strength attained by 8M, 12M, and 16M was 33.3, 36, and 38.08 respectively which was higher than normal GPC.
- Maximum tensile strength attained by 8M, 12M, and 16M was 3.56, 4.04, 4.77 respectively which was higher than normal GPC.
- Geopolymer concrete was more pore to acid attack compared to other chemicals exposure.
- Loss of strength was very less after the chloride exposure.

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