International Journal of Trend in Scientific Research and Development (IJTSRD)
Volume 8 Issue 4, Jul-Aug 2024 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470

Comparison of Mechanical Properties of Geopolymer Concrete vs Cement Concrete (Conventional Concrete)

Prakhar Srivastava, Mohd. Saahir, Raghav Garg, Prof. Umashankar Prajapat

Department of Civil Engineering, Raj Kumar Goel Institute of Technology,
Ghaziabad, Uttar Pradesh, India

ABSTRACT

Under the serious concerns of environmental degradation due to the greenhouse gas emissions of ordinary Portland cement (OPC,PPC) industry, geopolymer concretes have been qualified as a good alternative to PPC,OPC concretes. Geopolymer concretes, known by their good mechanical and durability properties, possess different fresh and hardened behaviours as compared to PPC,OPC concretes. This reason is one of the main obstacles that hinder the deployment of these concretes worldwide. Furthermore, geopolymer concretes developed in the literature are mostly based on fly ash while only few works were carried out on geopolymer concrete based on a blended mix of metakaolin (MK)/granulated blast furnace slag (GBFS). At fresh state, the workability evolution during the first hour after mixing was followed. At hardened state, mechanical strengths is investigated with a special attention to the early age behaviour.

KEYWORDS: *Plastic waste, Water absorption, Compressive strength of Concrete Geopolymer concrete; Metakaolin; Granulated blast furnace slag; Mechanical properties; Physical performances*

How to cite this paper: Prakhar Srivastava | Mohd. Saahir | Raghav Garg | Prof. Umashankar Prajapat "Comparison of Mechanical Properties of Geopolymer Concrete vs Cement Concrete (Conventional Concrete)" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-8 | Issue-4, August 2024, pp.15-26, URL: www.ijtsrd.com/papers/ijtsrd67112.pdf

IJTSRD67112

1. INTRODUCTION

Over the past few years, considerable attention has been paid to geopolymer concretes in order to limit the environmental impact of PPC,OPC industry on one hand, and to minimize the non-renewable raw materials supply on the other hand [Ma 2018].

Geopolymer binders are the result of the aluminosilicate precursor activation by an alkaline solution. Among several geopolymer formulations proposed in the literature, it has been shown that the blended metakaolin-granulated blast furnace slag based geopolymer provide suitable properties without any heat curing treatment [Hasnaoui 2019], which is generally used to accelerate the geopolymerization of fly ash based geopolymers and to enhance their matrix performances .

Geopolymer concretes are known by their resistance to high temperature and fire. In addition, they have showed a good mechanical and durability properties. However, they exhibit different fresh and hardened behaviours compared to PPC concretes and OPC, which raises serious questions about their application in the construction field. The comparison between geopolymer and PPC,OPC concretes have been addressed by several investigations. Nevertheless, the majority of the compared geopolymer concretes are based on fly ash as raw material with a binder volume different from that of reference PPC,OPC concretes. Moreover, the fast loss of workability and the drying shrinkage problems, which are the main issues that hinder the utilisation of these concrete worldwide, are often overlooked while focusing on the mechanical properties.

2. PROBLEM STATEMENT

- Cement production leads to high carbon-dioxide emission.
- It is the most consumed commodity in the world after water.
- Release of extensive heat when came into use.

- Cement is produced by calcination of limestone and burning of fossil fuels.
- Cement produced effect the environment as Air Pollution

Effect of Cement production plant and other industries waste on our environment:
2.1 Soil Pollution
2.2 Water Pollution
2.3 Air Pollution

2.1. SOIL POLLUTION
Formation of geopolymer leads to reduce the use of acres of land for combustion of Coal.

This phenomenon leads to soil pollution and removal of essential elements of soil presents(minerals in soil) necessary for the growth of nearby land it will affect the nearby area of that location very worse.

Fig. 2.1 coal combustion [source: google images]

2.2. WATER POLLUTION
Many industries waste are disposed off in the water bodies such as Fly ash, GBFS and many more admixtures that will contaminate the water bodies.

Due to the contamination all the minerals present in the water bodies will also be destroyed. It will adversely affect the the human being as many slum area used to get the water from the same water body and their health will be affected due to this unhealthy person's ration will also be going to increase.

Fig. 2.2 Plastic in water. [source: google images]

2.3. AIR POLLUTION
When cement is formed and as well as many other industries burn different-different compound(which turn into Fly Ash), hazardous compounds such as heavy metals, persistent organic pollutants (POP), and other harmful chemicals are released into the atmosphere and remain in ash waste residues. Asthma, endocrine disruption, and cancer have all been related to these substances. The CIEL anticipated in 2019 that plastic production and incineration will emit 850 million metric tons of greenhouse gases into the atmosphere, the equivalent of 189 coal-fired power stations. By 2050, this could increase to 2.8 giga tones of CO2 per year, the equivalent of 615 coal plants.

Fig. 2.3 Burning In clinker cause Air pollution.
[source: google images]

Fig. 2.4 C02 Emission from Cement manufacturing Plant Causes Air pollution.
[source: google images]

3. SCOPE OF PROJECT
Geopolymer as a binder provide us with a good opportunity to work on innovative things related to Construction industry and to try inventing some new civil engineering material that demonstrates some outstanding response. Following the preparation of Geopolymer concrete blocks, it is concluded that this project will be very beneficial to the residents of the

urban and coastal regions, and will have a significant impact on the environment.

Cement production and usage have some Co2 emisssion which pollutes the environment. We could add Fly Ash, MK, Rise Husk, and other ingredients in the future.

Geopolymer concrete blocks give us a chance to work on novel geopolymer binders projects and to try to design some new civil engineering materials that demonstrate some promises outstanding response in future industry and transforms the thoughts of the researchers, users and industries. As an example, consider going for

- Try to improve characteristics of construction materials by adding geopolymer in construction materials.
- Reusing the Fly ash and using as a construction material.

3.1. THIS STUDY AIMS TO PREPARE GEOPOLYMER BINDER AND USING THIS IN PLACE OF CEMENT IN A CONCRETE BLOCK.

The increase in problems while working with cement as binding material in building industry give us an idea to produce Geopolymer Concrete Blocks by using Fly Ash, Alkaline Indicator etc.

3.2. ADVANTAGES OF GEOPOLYMER AS BINDING MATERIAL

- **Reduced Carbon Footprint**: Geopolymer concrete has a lower carbon footprint compared to OPC concrete, making it a more sustainable option for construction projects.
- **Environmental Benefits**: Geopolymer concrete requires less energy and produces less CO2 emissions compared to OPC concrete, making it a more eco-friendly option.
- **Reduced Pollution**: The use of industrial waste by-products such as fly ash and slag in geopolymer concrete reduces the pollution burden on the environment, leading to both economic and environmental advantages.
- **Lower Heat of Hydration**: Geopolymer concrete has a lower heat of hydration compared to OPC concrete, which reduces the risk of thermal damage and improves the overall structural integrity of the concrete.
- **Increased Fire Resistance**: Geopolymer concrete has a higher fire resistance capacity compared to OPC concrete, making it a safer option for structures that are prone to fires.

Fig. 3.1 Advantages of Geopolymer as Binding Material [source: google images]

Fig. 3.2 A Building made by the Geopolymer Concrete [source: google images]

4. LITERATURE REVIEW

A. **Leong Sing Wong**, "Geopolymer concrete is produced from the geopolymerization process. It requires only an alkaline activator to catalyze its aluminosilicate sources such as metakaolin and fly ash, to yield geopolymer binder for the geopolymerization to take place.Its production expends less thermal energy and results in a smaller carbon footprint. ." **Should be cited as Leong Sing Wong et al. [1]**

B. **N A Lloyd,** "He had used fly ash and various materials in some proportion as follows and formed a geopolymer concrete.

Proportion is as follows:

20 mm aggregates = 277 kg/m3, 14 mm aggregates = 370 kg/m3, 7 mm aggregates = 647 kg/m3, fine sand = 554 kg/m3, low-calcium fly ash (ASTM Class F) = 408 kg/m3, sodium silicate solution (Na2O = 14.7%, SiO2 = 29.4%, and water = 55.9% by mass) = 103 kg/m3, and sodium hydroxide solution (8 Molar) = 41 kg/m3 (Note that the 8 Molar sodium hydroxide solution is made by mixing 11 kg of sodium hydroxide solids with 97-98% purity in 30 kg of water).

These test results have shown that the mean 7th day compressive strength was 56 MPa with a standard deviation of 3 MPa." **N A Lloyd et al. [2]**

C. **Abdul Aleem,** "He had tested the geopolymer concrete for precasting and make out the note regarding later usage of it.The Geopolymer Concrete shall be effectively used for the beam column junction of a reinforced concrete structure.

Due to the high early strength Geopolymer Concrete shall be effectively used in the precast industries, so that huge production is possible in short duration and the breakage during transportation." **Should be cited Abdul Aleem et al. [3]**

D. **Sandeep L. Hake**, "They studied for different curing temperature in oven curing, but only few researchers experimented with steam, membrane curing and no work was reported on accelerated curingaccelerated, membrane, natural and oven curing Investigation on the method of curing.

➢ They found that most of researcher used only oven heat curing for geopolymer concrete." **Should be cited as Sandeep L. Hake 2015 et al. [4]**

E. **Ahmad L., "**They had used many materials which are rich silica and alumina like as rice husk, red mud, fly ash, GGBS, etc. and compared the compressive and flexural strength of geopolymer concrete using these materials.

Blend with 70% GGBS+ 20% FA+ 10% SF has acquired the largest strength and hence is taken as an optimum blend for further field checking. Results still specified that flexural strength produced positive implement in comparison to tensile strength and this is owing to the obvious effect of SF in geopolymer concrete. " **Should be cited as Ahmad L et al. [5]**

F. **Neel Patel (4 April 2022),** "The goal of this project is to investigate the effects of different replacement levels of class Fly Ash (FA) and Ground Granulated Blast Furnace Slag (GGBS) on the micro characteristics of geopolymer concrete (GPC).

At 28 days' compressive strength, the starting material cost of Geopolymer Concrete (FA50%-GGBS50%) is roughly 27% more than that of Conventional Concrete (M25). **Should be cited as Neel Patel et al. [6]**

G. **Askarian M,** "Study on floating concrete by using lightweight aggregates is done. Cubes are casted and size is taken as 15cm X 15cm X 15cm. Compression test is conducted on the concrete cubes after the 7th day of the curing.

Lightweight concrete has low density than water and desirable strength as compared to conventional concrete. Different variations in proportions give varied strengths. Higher curing temperature resulted in larger compressive strength in geopolymer concrete.**Should be cited as Askarian M et al. [7]**

H. **Shashikant, Prince Arulraj G,** "The main constituent of geopolymer concrete is silicon and aluminium which are provided by thermally activated natural materials (e.g. Kaolinite) or industrial byproducts (e.g. Fly ash).

Replacement of fly-ash with 20% of ordinary Portland cement gives higher compressive strength than geopolymer concrete. "**Should be cited as Askarian M et al. [8]**

5. OBJECTIVE

5.1. PURPOSE OF THE PROJECT

➢ To prepare Geopolymer from the geopolymeriazatyion process.

➢ To compare compressive strength of Geopolymer concrete block with conventional block.

5.2. DIFFERENT STAGES OF PROJECT

1. Material Collection
2. Mixing with materials
3. Casting Blocks
4. Laboratory Testing

6. METHODOLOGY

A methodology is a set of methods, practices, processes, techniques, procedures, and norms that are used to create something. Methodologies in project are detailed and stringent, with a sequence of actions and activities for each phase of the project's life cycle.

6.1 Collection of Materials
6.2 Batching
6.3 Mixing
6.4 Molding
6.5 Curing
6.6 Testing

6.1. COLLECTION OF MATERIALS USED IN GEOPOLYMERIZATION

Source Material –Alumina Silicate materials having Alumina and silicate such as Fly ash, Silica Fume, MK etc. **Alkaline Liquids**: Combination of Sodium Hydroxide(NaOH) or Potassium Hydroxide(KOH) and Sodium Silicate or Potassium Silicate.

GEOPOLYMERIZATION PROCESS LOOKS LIKE……

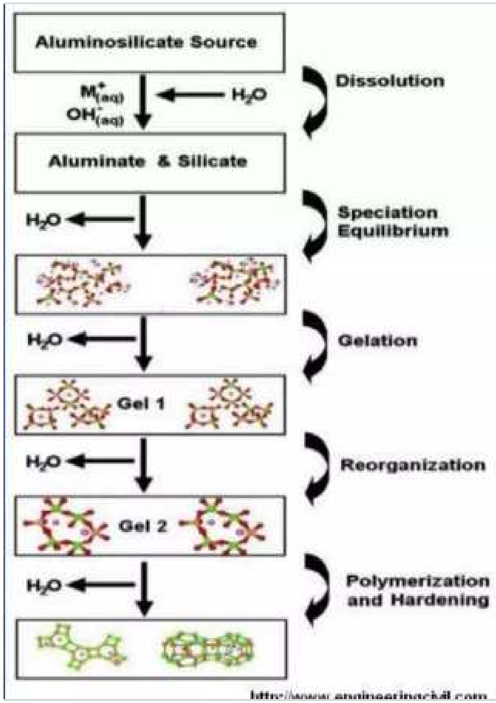

Fig 6.1 Formation process of geopolymer

6.2. BATCHING

Batching is the measurement of materials used to make brick. Following the collecting of materials, we segregate all material necessary for making the or adding admixtures to the Geopolymer Concrete, as well as check for any water content in the sample collected before proceeding with the burning.

6.3. MIXING

Material mixing is required for the manufacturing of homogenous and strong block. The mixing process must ensure that the mass is homogeneous, uniform in color, and consistent. Hand mixing and mechanical mixing are the two main forms of mixing. We used hand mixing in this project. till the complete plastic substance required for creating plastic block of one mix proportion is added into it. The geopolymer. are then carefully blended with a trowel before hardening. The combination has a very quick setting time; the bags are melted and river sand is added to it. When the sand is added, it is blended. As a result, the mixing process should not take too long.

6.3.1. Mixing Proportion

The concrete mix is created for Geopolymer Concrete blocks. The mix design is utilized to maximize the strength of the block.

In this project, we adopted hand mixing. until the entire Geopolymer as binder required for making Geopolymer Concrete Blocks of one mix proportion is added into it. then these .

			Concrete					Constituent (kg/m3)					
CEM I	fillers	Sp	GBFS	MK	SS		NaOH		W	FA	CA	W/C	W/S
OPSCC	314	105	4.6	-	-	-	-		177	914	820	0.43	-
GC	-	-	-	139	139	227	5.4		45	926	830	-	0.50

TABLE 6.3

6.4. MOLDING

We place the mix into the suitable mold when it has been properly mixed. After 24 hrs days, remove the block from the mould and allow it to cure.

6.5. CURING

After molding, the test specimens were allowed to dry for 24 hours. The specimens were placed in a curing tank and left to cure for 28 days.

Fig 6.5 Blocks Left for curing Source (Captured)

6.6. TESTING

Tests performed on Geopolymer Concrete Block and Cement Concrete Block are:

6.6.1. On Cement

A. Fineness Test
B. Normal Consistency Test
C. Dry Bulk Density and Water Porosity

6.6.2. On Geopolymer Concrete Blocks

A. Compressive strength Test
B. Dry Bulk Density and water Porosity
C. Slump Test

6.6.1. (a) Fineness Test (By Sieving)

Cement fineness is determined by screening a cement sample through a standard IS sieve. The weight of cement particles larger than 90 microns and the percentage of retained cement particles are computed. This is referred to as cement fineness.

Apparatus:

- Lid
- Pan
- Nylon brush
- 90-micron sieve
- Weighing balance – nearly weight 10 mg

Fig. 6.6.1 Fineness Test Apparatus [source: google images]

Procedure:

1. For the test sample, take 100 grams of cement and label it (w1).
2. Rub the cement particle with your hands thoroughly to remove any lumps.
3. Pour the 1 kg cement material into the sieve and shake it for 15 minutes, making sure that the sieving operation is done in all directions.
4. Now weigh the remaining cement on the sieve and record it as (w2).
5. Determine the proportion of the weight of cement retained on the 90 m sieve.

Note: The amount of cement retained on the 90 m sieve shall never exceed 10%, according to Indian Standard.

Percentage = (w2/1000) x w1.

Observation:

Observations	Trail 1	Trail 2	Trail 3
Weight of sample	100	100	100
Weight of residue of cement	6.28	4.63	7.24
% of fineness of cement	6.28%	4.63%	7.24%

Table 6.6 Observation Table of Fineness Test

Now their Average = (6.28% + 4.63% + 7.24%) / 3 = 6.05%

Result:

The Fineness value for the given sample of cement is 6.05%.

6.6.1. (b) Normal Consistency Test

Ordinary Portland cement has a standard consistency of about 30%. The normal consistency is the consistency of cement paste that permits the 10 mm diameter needle of the Vicat plunger to penetrate to 5 to 7 mm from the bottom of the conventional Vicat apparatus. Normal cement consistency is also known as standard cement consistency.

Apparatus:

- A Vicat apparatus with plunger 10 mm diameter.
- Weighing Balance
- Measuring glass 200 ml
- Flat Trowel
- Stop watch
- Spatula

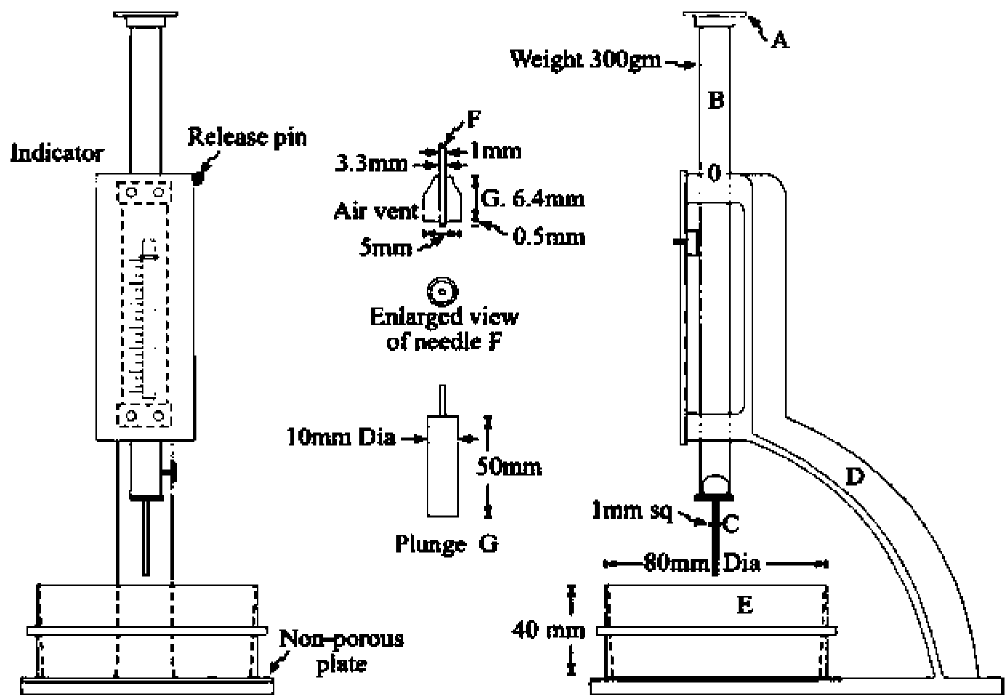

Fig. 6.6.2 Vicat Apparatus [source: google images]

Procedure:

1. Fix the Vicat equipment to a flat surface.
2. Now, take 250 gm of cement samples and mix it gently for 3 to 5 minutes with water by weight of cement.
3. Next, fill the Vicat mould with cement paste and remove any excess with a trowel.
4. Now, set the Vicat mould on the Vicat device and let the plunger to penetrate the cement paste.
5. Write down the gauge scale reading from the bottom of the Vicat mould.
6. Add water with a variable water ratio to the cement mixture until the reading is between 5 mm and 7 mm.

Observation:

Trial	Weight of Cement (in gm)	Quantity of Water (in ml)	Water percentage	Vicat's Penetration (in mm)
1	250	70	28 %	32
2	250	75	30 %	11
3	250	80	32 %	6

Table 6.7 Observation Table of Consistency Test

Result:

Achieved Normal Consistency is 32%.

6.6.1. (c) Dry Bulk Density and Water Porosity

Dry bulk density and water porosity were measured via the vacuum saturation method in accordance with the standard NF PN 18-459. For each concrete, three cylinders (11 × 5 cm) were tested.

The dry bulk density and the water porosity of OPSCC and GC are given in Tab. 3. As has been expected, GC shows a low bulk density as compared to OPSCC, since the density of Portland cement is higher than that of both GBFS and MK.

Although the air content in GC was lower than that of OPSCC at the fresh state, water porosity of GC was found to be around 20% higher than that of OPSCC. In fact, the extra water used to ensure the flowability of GC, plus the considerable amount of liberated water during the geopolymerization process are evaporated, which leads to create micropores in the geopolymer matrix and to increase the porosity.

The low porosity of OPSCC can be also interpreted by the incorporation of limestone fillers, which enhances the compactness.

Concretes	Dry bulk density (g/cm3)	Water porosity (%)
OPSCC	2.24±0.1	13.80±0.1
GC	2.20±0.1	16.49±0.1

6.6.2. (a) Compressive Strength Test

The compressive strength of the specimen brick shall be calculated after curing by using the following formula:

$$\text{Compressive strength} = \frac{\text{Applied Max load x 1000 (N)}}{\text{Cross sectional Area } (mm^2)}$$

The tests were being used by the UTM (Universal Testing Machine) for testing the block's compressive strength. Blocks are maintained for testing after curing process has ended.

Procedure:

1. Take the dimensions of block.
2. Clean the bearing surface of the testing machine
3. Place the specimen in the machine.
4. Rotate the movable portion gently by hand so that it touches the top surface of the specimen.
5. Apply the load gradually without shock and continuously.
6. Record the maximum load at which specimen fails.

Fig. 6.6.3 Compressive Strength Test using UTM [source: captured]

6.6.2. (c) Slump Test

Fig 6.6.4 Slump Test

7. MATERIALS

Plastic paver block uses the same material as conventional concrete; plastic pieces is main material for making this block.

- Cement
- Stone Chips
- Dust
- Plastic Pieces
- Water

7.1. CEMENT

Cement is generally characterized as a material with very good adhesive and cohesive characteristics that allow it to connect with other materials to form a compact mass.

1. Ordinary Portland Cement
2. Pozzolana Portland Cement

The results of tests on various physical properties of cement are shown in test data of materials:

S. No.	Tests	Standards
1.	Initial Setting Time	30 minutes
2.	Final Setting Time	600 minutes
3.	Fineness	Not less than 90%
4.	Specific Gravity	3.10 to 3.15
5.	Standard Consistency	30% to 35%

Table 7.1 Physical Properties of Cement

7.2. STONE CHIPS

Stone chips are larger or less than 4.75 mm in size, or nearly so. The major rationale for adding stone chips in plastic paver blocks is to increase the block's strength. 4.75 No sieve is employed in this investigation. 4.75 No sieve is used in the manufacture of plastic paver blocks. Stone chips are utilized in plastic paver blocks to increase the strength of the block. Fine aggregate from crushed sand: Instead of river sand, manufactured sand that meets the specifications of IS 383- 1970 is used to construct smart dynamic concrete. Crushed sand is used to reduce the number of pores in the block. binding substance.

7.3. DUST

Dust is made up of small solid matter particles. On Earth, it is mainly made up of particles in the atmosphere that come from numerous sources, such as wind-lifted soil. Dust is utilized in our paver block to limit the number of pores.

7.4. GEOPOLYMER CONCRETE

- Coarse aggreagate.
- Fine aggregate-sand or bottom ash can be used.
- Admixture-superplasticizers (napathalene based or naphthalene sulphonate based).
- Alkaline activators
- Alkaline activation is process of mixing powdery aluminosilicate with an alkaline activator.
- It produce a paste which sets and hardens within short duration.
- Sodium Silicate, NaOH and NA2SiO3, K2SiO3,GGBS,Slica –fume.

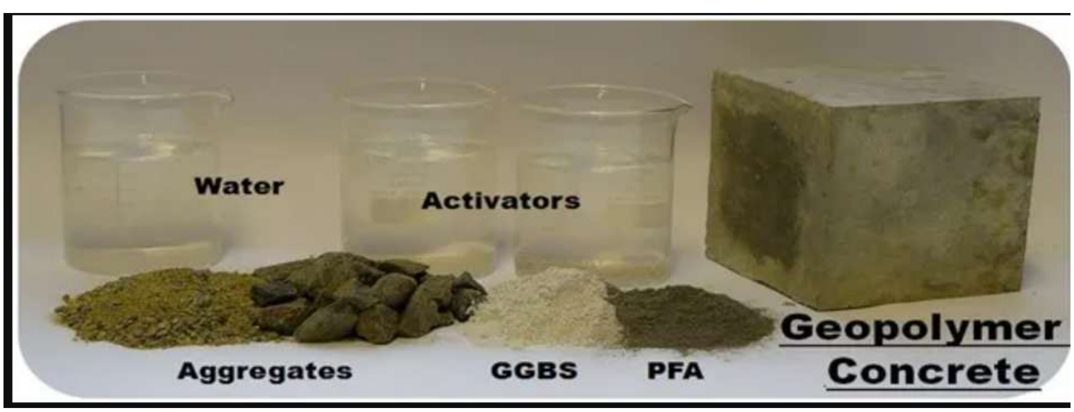

Fig 7.1

7.5. WATER
Portable water is used to cure Geopolymer Concrete Block. The ingredients listed above are used to produce cement concrete and geopoltymer concrete blocks.

8. RESULTS
8.1. FINENESS TEST ON CEMENT (BY SIEVE)

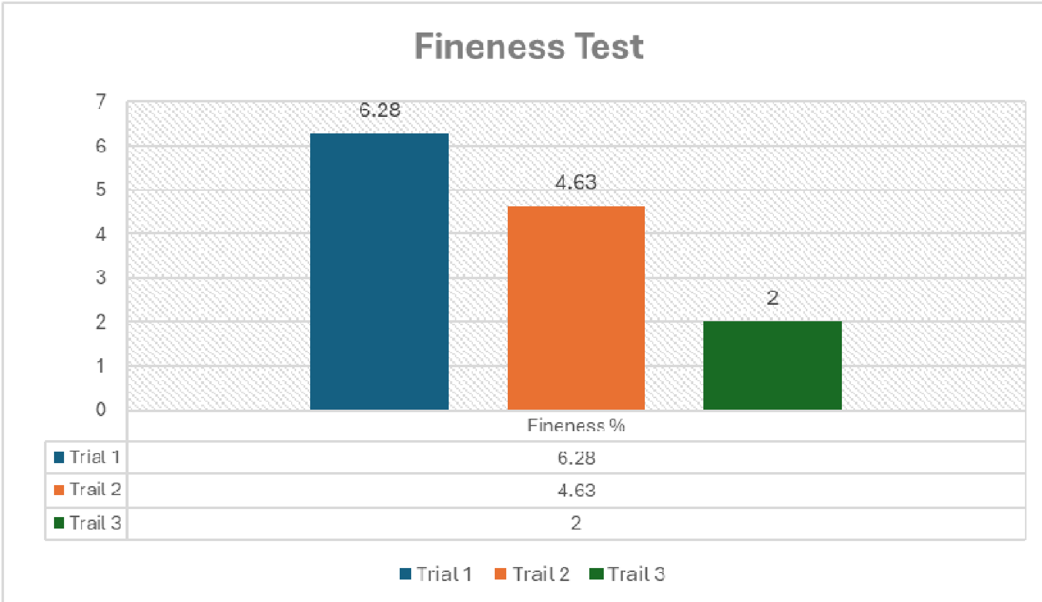

Fig. 8.1 Fineness Test Result

"The Average Fineness value for the given sample of cement is 6.05%."

8.2. NORMAL CONSISTENCY TEST ON CEMENT

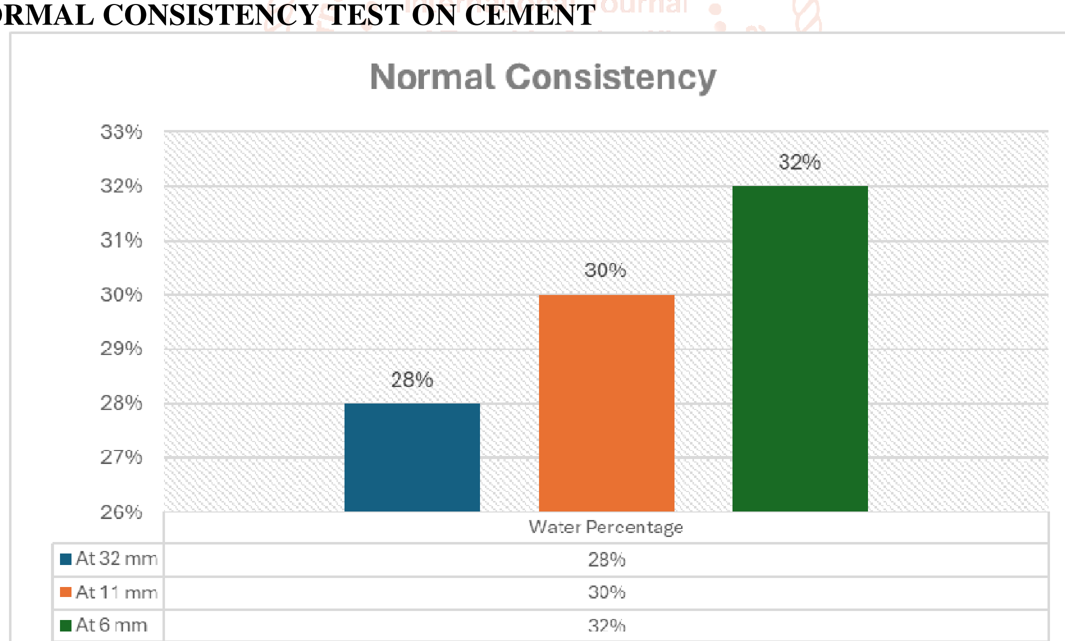

Fig. 8.2 Normal Consistency Test Result

"Achieved Normal Consistency is 32%."

8.3. COMPRESSIVE STRENGTH TEST ON GEOPOLYMER CONCRETE BLOCK

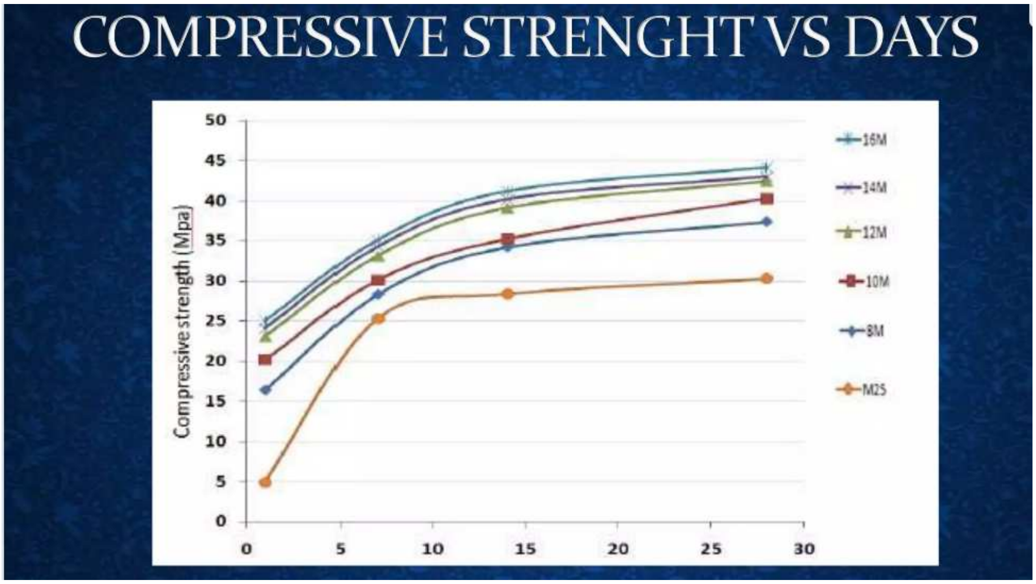

Fig 8.3 Compressive Strength Test Result

8.4. SLUMP TEST

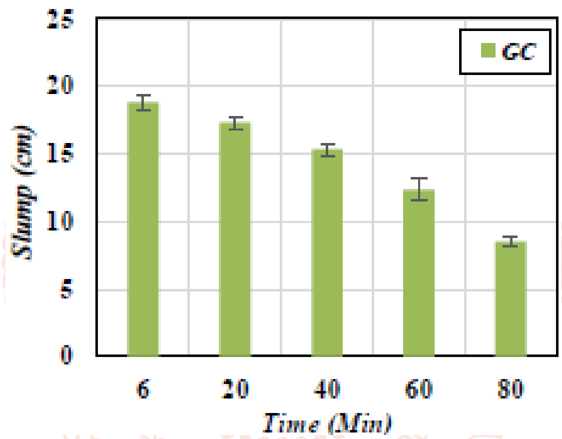

Fig 8.4

9. CONCLUSION

Technology of Geopolymer offers a good approach for utilization of industrial byproducts (waste). The formation and properties of geopolymers depend on the chemical and physical characteristics of raw materials, alkali activators and curing conditions. Different models have been proposed from time to time. Geopolymer with dense structure gives high early mechanical strength and good resistance to aggressive atmosphere.

In terms of compressive strength, geopolymer concrete has been shown to have similar or even higher compressive strengths compared to cement concrete. For example, a study found that self-compacting geopolymer concrete with zero cement and zero superplasticizers cured under ambient conditions had a compressive strength of 40 MPa (5,800 psi) after 28 days of curing, which is comparable to that of M40 grade conventional concrete. Another study reported that geopolymer concrete with a compressive strength of 60 MPa (8,700 psi) after 28 days of curing, which is higher than the typical compressive strength of cement concrete.

In conclusion, geopolymer concrete has been shown to have similar or higher compressive strengths compared to cement concrete. The compressive strength of geopolymer concrete is influenced by factors such as the type of aluminosilicate material, the amount of activator used, and the curing conditions. While cement concrete is still widely used, geopolymer concrete offers a more sustainable and environmentally friendly alternative with improved properties.

10. FUTURE SCOPE

Future Research Directions

- **Nanomodified geopolymer concretes**: Research is ongoing to develop nanomodified geopolymer concretes with improved properties, such as enhanced mechanical strength and durability.
- **3D printing using geopolymer concrete**: The use of geopolymer concrete in 3D printing technology has the potential to revolutionize the construction

industry by enabling the creation of complex structures with reduced material waste.

- **Geopolymer concrete reinforced with steel bars**: Research is being conducted to develop geopolymer concrete reinforced with steel bars, which could provide improved mechanical properties and durability.
- **Assessment of geopolymer concrete technology on global warming potential**: Studies are being conducted to evaluate the environmental impact of geopolymer concrete production and its potential to reduce global warming potential.

The future scope of geopolymer concrete is promising, with its potential to reduce environmental impact, improve mechanical properties, and reduce costs. While there are challenges and limitations to its adoption, ongoing research and development are addressing these issues. As the construction industry continues to evolve, geopolymer concrete is likely to play an increasingly important role in shaping the future of sustainable construction.

REFRENCES

[1] [Bakri 2013] Bakri, S.J.; Luqman, A.; Pathik, B.; Chandrasekaran, K.; Is carotid ultrasound necessary in the clinical evaluation of the asymptomatic Hollenhorst plaque?. Ophthalmology, 2013, 120(12), 2747-2748.

[2] [Chi 2012] Chi, M.C.; Chang, J.J.; Huang, R.; Strength and drying shrinkage of alkali-activated slag paste and mortar. Advances in Civil Engineering, 2012, 2012, 1-7.

[3] [Davidovits 2008] Davidovits, J.; Geopolymer chemistry and applications. Geopolymer Institute, 2008.

[4] [Davidovits 2013] Davidovits, J.; Geopolymer cement. Geopolymer Institute, 2013, 21, 1-11.

[5] [Hasnaoui 2019] Hasnaoui, A.; Ghorbel, E.; Wardeh, G.; Optimization approach of granulated blast furnace slag and metakaolin based geopolymer mortars. Construction and Building Materials, 2019, 198, 10-26.

[6] [Lee 2016] Lee, N.K.; Kim, E. M.; Lee, H.K.; Mechanical properties and setting characteristics of geopolymer mortar using styrene-butadiene (SB) latex. Construction and Building Materials, 2016, 113, 264-272.

[7] [Mobili 2017] Mobili, A.; Belli, A.; Giosuè, C.; Telesca, A.; et al.; Calcium sulfoaluminate, geopolymeric, and cementitious mortars for structural applications. Environments, 2017, 4(3), 64. ICBBM2019 AJCE - Special Issue Volume 37 – Issue 2 132

[8] [Noushini, A.; Aslani, F.; Castel, A.; Gilbert, R.I.; et al].;. Compressive stress-strain model for low-calcium fly ash-based geopolymer and heat-cured Portland cement concrete. Cement and Concrete Composites, 2016, 73, 136-146.

[9] [Pavithra 2016] Pavithra, P.; Reddy, M.S.; Dinakar, P.; Rao, B.H. et al.; A mix design procedure for geopolymer concrete with fly ash. Journal of Cleaner Production, 2016, 133, 117-125.

[10] [Saavedra 2017] Saavedra, W.G.V.; de Gutiérrez, R. M.; Performance of geopolymer concrete composed of fly ash after exposure to elevated temperatures. Construction and Building Materials, 2017, 1554, 229-235.

[11] American Coal Ash Association. Coal Combustion Product Production & Use Survey Report; American Coal Ash Association: Farmington Hills, MI, USA, 2018.

[12] Chindaprasirt, P.; Jaturapitakkul, C.; Chalee, W.; Rattanasak, U. Comparative Study on the characteristics of fly-ash and bottom-ash geopolymers. Waste Manag. 2009, 29, 539–543.

[13] Sinha, D.K.; Kumar, A.; Kumar, S. Development of Geopolymer Concrete from Fly Ash and Bottom Ash Mixture. J. Trans. Indian Ceram. Soc. 2014, 73, 143–148.

[14] Ul Haq, E.; Padmanabhan, S.K.; Licciulli, A. Synthesis and characteristics of fly ash and bottom ash based geopolymers—A comparative study. Ceram. Int. 2014, 40, 2965–2971.

[15] Duxson, P.; Fernández-Jiménez, A.; Provis, J.L.; Lukey, G.C.; Palomo, A.; van Deventer, J.S. Geopolymer technology: The current state of the art. J. Mater. Sci. 2007, 42, 2917–2933.

[16] McLellan, B.C.; Williams, R.P.; Lay, J.; Van Riessen, A.; Corder, G.D. Costs and carbon emissions for geopolymer pastes in comparison to ordinary Portland cement. J. Clean. Prod. 2011, 19, 1080–1090.

[17] Habert, G.; De Lacaillerie, J.D.E.; Roussel, N. An environmental evaluation of geopolymer based concrete production: Reviewing current research trends. J. Clean. Prod. 2011, 19, 1229–1238