EXPERIMENTAL STUDY OF FACTORS INFLUENCING COMPRESSIVE STRENGTH OF GEOPOLYMER CONCRETE

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Abstract - *Manufacture of Portland cement produces large of volumes of carbon dioxide and other gases. Releasing these gases causes atmospheric pollution and subsequent environmental degradation. Finding a suitable alternative solution to mitigate the environmental degradation caused by using Portland cement is very important for environmental sustainability. On the other side, fly ash is the waste material of coal based thermal power plant, available abundantly but pose disposal problem. There are environmental benefits in reducing the use of Portland cement in concrete, and using a cementitious material, such as fly ash. Geopolymer concrete is new sustainable concrete which is manufactured by replacing cement 100% with processed fly ash which is chemically activated by alkaline solutions made from sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH). This thesis presents the effect of several factors like alkaline liquid to fly ash ratio, molarity of NaOH, curing hours and curing temperature on the compressive strength of fly ash based geopolymer concrete. Fly ash is taken as the basic material to develop the geopolymer concrete and it is activated by the alkaline solution of sodium silicate and sodium hydroxide. The test variables were molarities of sodium hydroxide (NaOH) 12M, 4M, 16M, and 18M, ratio of NaOH to sodium silicate (Na_2SiO_3) 2.5, alkaline liquid to fly ash ratio 0.35, 0.40, 0.45 and 0.50 were used in the present study. The experiment were also conducted on GPC cubes for curing temperature of 75° C, 90° C and 105° C with curing period of 12, 18 and 24 hours by adopting hot oven curing method. The test result indicated that the compressive strength increases with increase in molarity of NaOH but it decreases with increases in water content. It is also absorbed that compressive strength is remarkably affected by the curing hours and curing temperature. When curing temperature is increases, the compressive strength is also increases and it requires less curing period to gain the higher strength.*

1.INTRODUCTION

1.1 General

Production of cement is one of the major contributors to the emission of green-house gasses like carbon dioxide. Day by day the World's Portland cement production increases with the increasing demand of construction industry. Cement is the main ingredient for the production of concrete. But the production of cement requires large amount of raw material. During the production of cement burning of lime stone take place which results in emission of carbon dioxide (CO_2) gas into the atmosphere. There are two different sources of CO_2 emission during cement production. Combustion of fossil fuels to operate the rotary kiln is the largest source and other one is the chemical process of burning limestone. In 1995 the production of cement was 1.5 billion tons which goes on increasing up to 2.2 billion tons in 2010. One ton of production of cement causes one ton of emission of CO_2 into the atmosphere. It is estimated that the emission of carbon dioxide due to cement production to be nearly about 7% of the total production of carbon dioxide, which make required to go for other greener alternative binder from Portland cement [1].

Fly ash is the waste residue that results from the combustion of coal in thermal power station is available at large scale all over the world. In India more than 100 million tons of fly ash is produced annually. Out of this, only 17 – 20% is utilized either in concrete or in stabilization of soil. Most of the fly ash is disposed off as a waste material that coves several hectors of valuable land. As fly ash is light in weight and easily flies, this creates severe health problems like asthma, bronchitis, and so forth. There are environmental benefits in reducing the use of Portland cement in concrete, and using a by-product material, such as fly ash as a substitute. With silicon and aluminium as the main constituents, fly ash has great potential as a cement replacing material in concrete. For every ton of fly ash used in place of Portland cement saves about a ton of carbon dioxide emission to the atmosphere [2].

Davidovits proposed a new term geopolymer in 1978 to represent the mineral polymers resulting from geochemistry. Geopolymers are members of the family of inorganic polymers in which the mineral molecules are linked with covalent bond. Geopolymers are produced by source materials or by-product of geological origin that is rich in silica and alumina like fly-ash when react with alkaline solution at elevated temperature. The chemical reaction that takes place in this case is polymerization, so this binder is called geopolymer. Geopolymer concrete is a new type of concrete in which cement is fully replaced by the pozzolanic materials that is rich in Silicon (Si) and Aluminium (Al) like fly ash. It is activated by highly alkaline liquids to produce the binder which binds the aggregates in concrete when subjected to elevated temperature. The concrete made with such industrial waste is eco-friendly and so it is called as "Green concrete".

The chemical composition of the geopolymer material is similar to zeolitic materials, but the microstructure is irregular. The polymerization process involves a fast chemical reaction under alkaline condition on Si-Al minerals, those results in a three-dimensional polymeric chain and ring structure existing of Si-O-Al-O bonds. Poly (sialates) as the resulted material has the empirical formula as below:

$$M_n [-(SiO_2)_z-AlO_2]_n . wH_2O$$

Where: M = the alkaline element or cation such as potassium, sodium or calcium
n = the degree of polycondensation or polymerisation
z = 1,2,3 or higher

The main concept behind this geopolymer material is the polymerization of the Si-O-Al-O bond which develops when Al-Si source materials like Fly ash is mixed with alkaline liquids. The geopolymer can be one of these basic form:

- Poly (sialate), [-Si-O-Al-O-]
- Poly (sialate-siloxo), [-Si-O-Al-O-Si-O-]
- Poly (sialate-disiloxo), [-Si-O-Al-O-Si-O-Si-O-]

The schematic formation of geopolymer material can be shown by equations (1) and (2).

n(Si2O5, Al2O2) + 2nSiO2 + 4nH2O +NaOH/KOH
(Si-Al materials) |
|
Na+, K+ + n(OH)3-Si-O-Al--O-Si-(OH
|
(OH)2
(Geopolymer precursor) ----------------------[1]

n(OH)3-Si-O-Al--O-Si-(OH)3 + NaOH/KOH
| |

(OH)2 |
(Na+, K+)-(-Si-O-Al--O-Si-O-) + 4nH2O
| | |
O O O
(Geopolymer Backbone) -----------------------[2]

The exact mechanism of setting and hardening of the geopolymer material is not clear. However, most proposed mechanism consists the chemical reaction may comprise the following steps:

1. Dissolution of Si and Al atoms from the source material through the action of hydroxide ions.

2. Transportation or orientation or condensation of precursor ions into monomers.

3. Setting or polymerisation of monomers into polymeric structures [3].

Water is released during the chemical reaction that occurs in the formation of geopolymers. This water, released from the geopolymer concrete during the rest period, oven curing and further drying periods, leaves behind discontinuous nano-pores in the concrete, which provide benefits to the performance of geopolymer concrete. The water in a geopolymer mixture, plays no role in the chemical reaction that takes place; it provides the workability to the mixture during handling [4]

1.2 Constituents of Geopolymer Concrete

There are two main constituents of Geopolymers, namely the source materials and the alkaline liquids. By-product materials such as fly ash, silica fume, slag, rice husk ash, GGBS, red mud, etc can be used as source materials.
The most common alkaline liquid used in geopolymer concrete is a combination of sodium hydroxide or potassium hydroxide and sodium silicate or potassium silicate.
It is important that the alkaline liquid is prepared by mixing both the solutions together at least 24 hours prior to use. The mass of NaOH solids in a solution depend on the molarity of the solution.

1.3 Advantages of Geo-Polymer Concrete

- High early compressive strength gain
- Good abrasion resistance
- Rapid controllable setting and hardening
- Fire resistance up to 1000 degree centigrade and no emission of toxic fumes when heated
- High level of resistance to a range of different acids and salt solutions
- Low thermal conductivity and low shrinkage
- Impermeable like normal OPC concrete
- Bleed free
- High surface definition that replicates mould patterns [5].

1.4 Objective of the Present Study

To study the effect of factors like Molarity, alkaline liquid to fly ash ratio, curing hour and curing temperature that affects the compressive strength of fly ash based geopolymer concrete.

2 EXPERIMENTAL PROGRAMME

2.1 Materials Used

A. Fly Ash

In this study, fly ash (ASTM Class F) obtained from Rosa Thermal Power Station Shahajahanpur was used. The chemical and physical properties of fly ash shown below in table 2.1 and 2.2 respectively.

Table-1: Chemical Properties of Fly Ash

Characteristics	Observed Value (%)	Range Specified for Class-F Fly ash (as per ASTM C-618)
Silicon dioxide (SiO_2)	56.31	46-60
Alumina (Al_2O_3)	31.82	21-28
Iron oxide (Fe_2O_3)	4.77	5-9
Calcium oxide (CaO)	2.33	0.5-8
Magnesium Oxide (MgO)	1.09	0.2-4
Sulphur trioxide (SO_3)	0.16	0-0.4
Sodium oxide (Na_2O)	0.042	0-0.3
Potassium oxide (K_2O)	0.013	0-0.2
Titanium (TiO_2)	2.01	1-2.1

Table-2: Physical Properties of Fly Ash

Characteristics	Observed Value
Specific Gravity	2.18
Fineness(m^2/kg)	340
Lime reactivity(N/mm^2)	4.8
Loss on Ignition(% by mass)	0.70
Soundness by auto-cleave method	0.12

B. Alkaline Solution

The combination of sodium silicate to sodium hydroxide was used as alkaline solution in the present study and the ratio of both was maintained to 2.5 throughout the study. The solution was prepared one day prior to be used.

I. Sodium Hydroxide

Generally NaOH is available in market in pellets or flakes form with 96% to 98% purity where the cost of the product depends on the purity of the material. Sodium hydroxide in pellet form was used in this work of 97% purity. The solution of NaOH was formed by dissolving it in deionised water for the molarity of 12M, 14M, 16M & 18M. The NaOH solution was prepared 24 hours before casting of specimens.

II. Sodium Silicate

Sodium Silicate (Na_2SiO_3) is also known as waterglass which is available in the market in gel form and also in the solid form. Sodium silicate in gel form was used in this study having 31% of SiO_2, 14% of Na_2O & 55% of H_2O. The ratio of silicon dioxide (SiO_2) and sodium oxide (Na_2O) in sodium silicate gel is 2.21.

Fig.-1: Sodium Hydroxide Pellets

Fig.-2: Sodium Silicate Liquid

2.2 Mix Proportioning Details

The geopolymer concrete was made for sixteen different mix proportion of fly ash, alkaline solution, fine aggregate and coarse aggregate with variation in alkaline liquid to fly ash ratio as 0.35, 0.40, 0.45 & 0.50 for molarities of 12M, 14M, 16M, &18M.

Table-3: Mix details of fly ash based geopolymer Concerte

S.No.	Alkaline sol./Fly ash ratio	Fly ash (Kg/m3)	
Mix-1 Mix-2 Mix-3 Mix-4	0.35	580	
Mix-5 Mix-6 Mix-7 Mix-8	0.40	580	

Mix-9 Mix-10 Mix-11 Mix-12	0.45	580	546
Mix-13 Mix-14 Mix-15 Mix-16	0.50	580	536

Coarse aggregate (Kg/m3)	Sodium hydroxide (Kg/m3)	Sodium silicate (Kg/m3)	Molarity (M)
1051	58	145	12 14 16 18
1032	66.28	165.71	12 14 16 18
1013	74.57	186.43	12 14 16 18
994	82.86	207.14	12 14 16 18

2.3 Mixing Casting and Curing of Geopolymer Concrete

In the laboratory, the fly ash and the aggregates was first mixed together in dry state 2-4 minutes to get homogeneous mix. The alkaline solution was mixed with the extra water and this liquid components were added to the mixed aggregate and the mixing continued usually for another 12 - 15 minutes so that binding paste covered all the aggregates and mixture become homogeneous and uniform in colour. The fresh concrete could be handled up to 120 minutes without any sign of setting and without any degradation in the compressive strength.

After the mixing is done, the fresh geopolymer concrete was filled in the moulds in three layers with required compaction same as the usual methods used in the case of Portland cement concrete and the specimens are kept on a vibrating table so that to minimize amount of voids present in the fresh concrete. The workability of the fresh concrete was measured by means of the conventional slump test.

For the polymerisation process, the high temperature curing is required in geopolymer concrete. The required temperature may be provided either by oven curing or by steam curing. In the present study, oven curing was used. The GPC cubes were placed in an oven for the period of 12, 18 and 24 hours. After the curing period, the test specimens were left in the moulds for at least 5-6 hours in order to avoid a major change in the environmental conditions. After de-moulding, the concrete specimens were allowed to become air-dry in the laboratory until the day of the compressive strength testing.

Fig.-4: Addition of Alkaline Solution

Fig.-5: Fresh Geopolymer Concrete

Fig.-6: Oven Curing of GPC Cubes

2.4 Testing of Geopolymer Concrete Cubes

The geopolymer hardened concrete cubes were tested for compressive strength. The compressive strength test was performed according to IS-5160: 1959. Cube specimens of size 150mm × 150mm× 150mm were prepared for each mix. After one day of rest period, they were cured in oven for 12, 18 & 24 hours and were demoded and stored until the day of testing. For specimens with uneven surfaces, capping was used to minimize the effect of stress concentration. The compressive strength reported is the average of three results obtained from three identical cubes.

Fig.-7: Compressive Strength Testing of GPC Cubes

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1 Effect of Molarity and AL (Alkaline Liquid)/Fly-Ash Ratio on the Compressive Strength of GPC

Table-4: Compressive Strength of Alkaline solution to fly ash ratio=0.35

Mix No.	Molarity (M)	Compressive Strength (MPa) @ 7 days	Average comp. Strength (MPa)
Mix -1	12	26.60	26.30
		24.90	
		27.40	
Mix-2	14	29.70	31.2
		32.90	
		30.90	
Mix-3	16	35.60	34.8
		32.70	
		36.10	
Mix-4	18	31.70	33.9
		35.90	
		34.10	

Chart-1: Effect of molarity on compressive strength of geopolymer concrete for AL/Fly-ash ratio 0.35

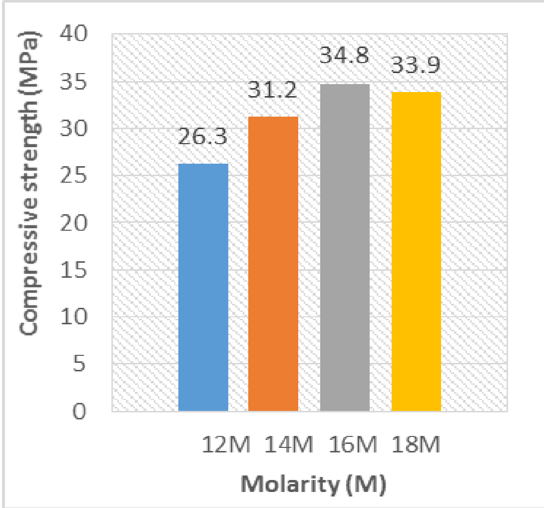

Table-5: Compressive strength for Alkaline solution to fly ash ratio=0.40

Mix No.	Molarity (M)	Compressive strength (MPa) @ 7 days	Average comp. Strength (MPa)
Mix-5	12	34.8	32.1
		33.2	
		28.4	
Mix-6	14	36.4	36.7
		34.6	
		39.1	
Mix-7	16	41.8	40.3
		38.4	
		40.7	
Mix-8	18	37.9	40.8
		42.9	
		41.7	

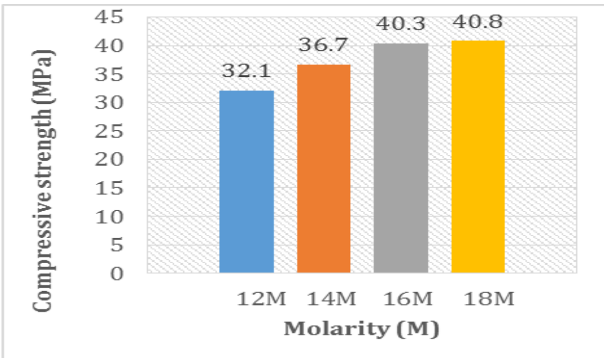

Chart-2: Effect of molarity on compressive strength of geopolymer concrete for AL/Fly-Ash ratio 0.40

Table-6: Compressive strength for Alkaline liquid to fly ash ratio=0.45

Mix No.	Molarity (M)	Compressive Strength (MPa) @ 7 days	Average comp. Strength (MPa)
Mix-13	12	33.4	33.4
		35.2	
		31.9	
Mix-14	14	37.9	37.0
		35.2	
		38.1	
Mix-15	16	39.2	39.7
		41.1	
		38.8	
Mix-16	18	37.6	38.9
		40.1	
		39.2	

Table-7: Compressive strength for Alkaline liquid to fly-ash ratio=0.50

Mix No.	Molarity (M)	Compressive Strength (MPa) @ 7 days	Average comp. Strength (MPa)
Mix-9	12	36.2	36.8
		39.2	
		35.1	
Mix-10	14	42.5	40.4
		38.2	
		40.6	
Mix-11	16	44.4	43.5
		43.2	
		42.9	
Mix-12	18	43.4	43.7
		42.9	
		44.8	

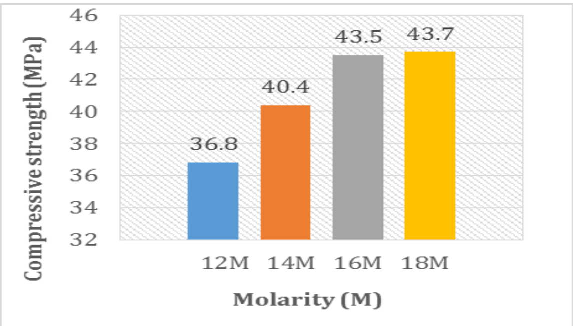

Chart-3: Effect of molarity on compressive strength of geopolymer concrete for AL/Fly-ash ratio 0.45

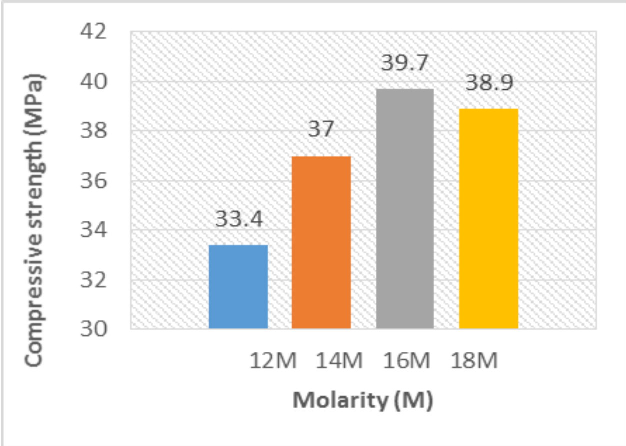

Chart-4: Effect of molarity on compressive strength of geopolymer concrete for AL/Fly-ash ratio 0.50

The results indicated that the compressive strength increases with increase in molarity of NaOH solution upto 16M but beyond the molarity 16M, slightly variation in compressive strength is observed for the molarity 18M. Results also show that the compressive strength is increases with increment in alkaline liquid to fly ash ratio but for ratio value beyond 0.45, slightly decrease in compressive strength is observed. It means when this ratio is increases, the water content in the solution is increases which affect the compressive strength.

3.2 Effect of Curing Hour and Curing Temperature on Compressive Strength of GPC

Table-8: Compressive strength of GPC specimens at curing temperature of 75°C

Mix No.	Curing Tempe - rature (°C)	Curing Period (hours)	Compressiv e Strength (MPa)	Mean Compressiv e Strength (MPa
Mix -11	75	12	26.9	27.8
			29.2	
			27.5	
		18	34.6	34
			32.2	
			35.4	
		24	37.2	37.4
			39.9	
			35.1	

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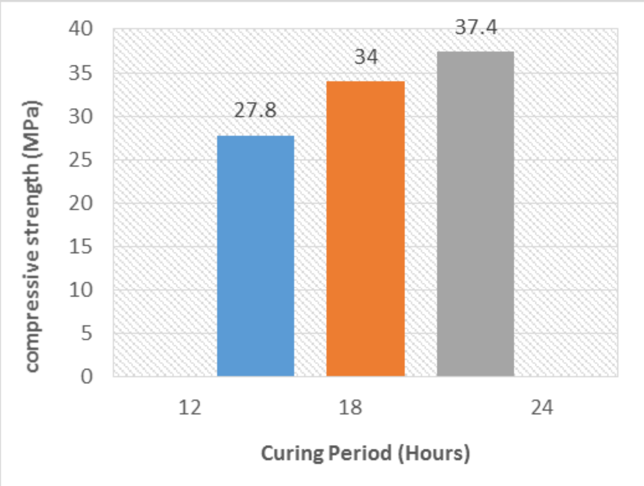

Chart-5: Effect of curing hours on compressive strength of GPC for temperature 75°C

Table-9: Compressive strength of GPC specimens at curing temperature of 90°C

Mix No.	Curing Tempe-rature (°C)	Curing Period (hours)	Compressive Strength (MPa)	Mean Compressive Strength (MPa)
Mix-11	90	12	38.1	38.4
			40.3	
			36.7	
		18	42.2	42
			40.1	
			43.7	
		24	44.4	43.5
			43.2	
			42.9	

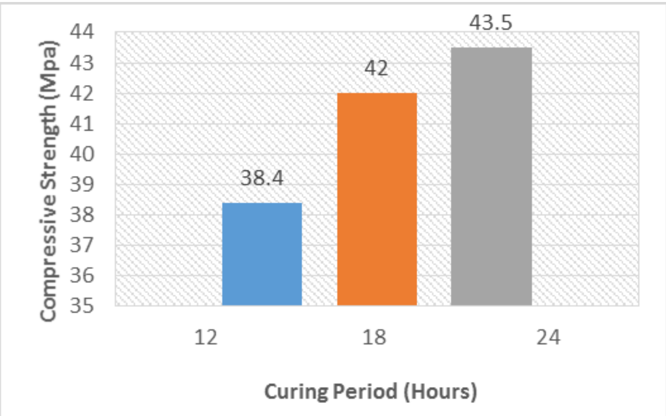

Chart-6: Effect of curing hours on compressive strength of GPC for temperature 90°C

Table-10: Compressive strength of GPC specimens at curing temperature of 105°C

Mix No.	Curing Tempe-Raptur e (°C)	Curing Period (hours)	Compressiv e Strength (MPa)	Mean Compressiv e Strength (MPa)
Mix -11	105	12	43.9	42.9
			40.2	
			44.7	
		18	40.7	41.2
			42.1	
			40.9	
		24	37.9	38.7
			40.1	
			38.1	

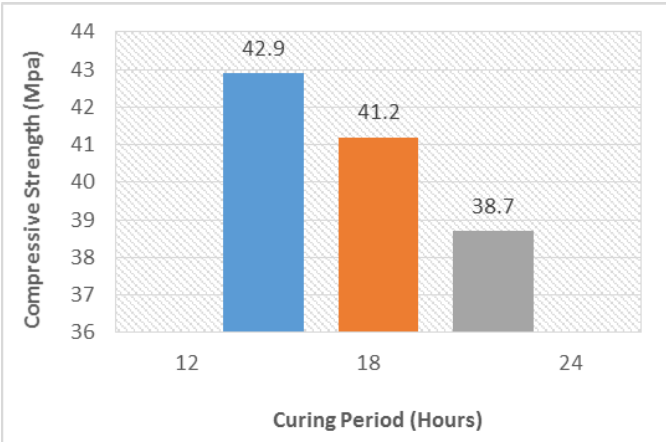

Chart-7: Effect of curing hours on compressive strength of GPC for temperature 105°C

The compressive strength of GPC concrete is observed to increases at curing temperatures 75°C and 90°C for 12, 18 and 24 hr of curing period, but when curing is done at 105°C, compressive strength increasing up to 12 hr of curing, after that it start decreasing. Hence it is observed that when curing temperature is increased, it requires less curing hours to gain same compressive strength.

3. CONCLUSIONS

Based on the experimental work reported in this study, the following conclusions are drawn:

1. Compressive strength of geopolymer concrete is increases with increase in alkaline solution to fly ash ratio upto 0.45, but at 0.50 the strength slightly decreases because of increase in water content present in alkaline solution.

2. Compressive strength of GPC is also increases with increase in concentration of NaOH up to 16 M, but for 18 M, there is no remarkable changes in compressive strength but the cost of production is increases.
3. At 75°C temperature, the compressive strength increases gradually with the increases in curing period up to 24 hr.
4. At 90°C temperature, the samples gained 95 % strength at 18 hours of curing, beyond this curing period, minor increment in strength is recorded.
5. Compressive strength of GPC samples at 105°C temperature certain increases up to 12 hours of curing period but it decreases when it cured for 24 hr at 105°C.

It has been observed from the above discussion that there are various parameters that affects the compressive strength of the geopolymer concrete. Therefore, parametric study of various factors influncing the compressive strength of the geopolymer concrete is strongly recommended first before conducting any further investigations related to mechanical properties and durability of the geopolymer concrete in order to get the desirable benefits from the further investigations.

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