Geopolymer Concrete a Sustainable Concrete for Future Construction

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Geo-polymer Concrete- a sustainable concrete for future construction

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Abstract

The production of the cement concrete industry has grown in this modern world and is considered one of the major contributors to global pollution. The production of cement used as binder requires a high-temperature combustion process which contributes to the increase of the amount of CO2 in the atmosphere leading to one of the major threats to the planet (climate change) and the consumption of natural resources. Many countries begin to impose carbon taxes as raw materials deplete over time. To reduce and eliminate greenhouse gas emissions, numerous studies have been conducted to develop an innovative and environmentally beneficial building material names Geopolymer concrete. It is vital to replace cement with a by-product substance abundant in silicon and aluminium such as fly ash, rice husk ash, silica fume, GGBS, etc. activated by a high alkaline solution to bind loose aggregates, fine aggregates, and other unreacted materials in geopolymer concrete in order to make a progress in the qualities of concrete and reduce natural resource uses. The current study focused on the impact of various parameters such as molarity of sodium hydroxide (8-16M), and curing temperature(30-90^{0}C) on different mechanical properties such as workability, compressive strength and tensile strength of geopolymer concrete.

Keywords: NaOH Molarity, geopolymer concrete, compressive strength, tensile strength, super-plasticizers.

Introduction

Climate change has become a great problem for the world as a large quantity of rising CO_2 gas gets discharged into the atmosphere [1]. The cement sector is one of the major contributors to world carbon emissions, hence cement production is under scrutiny and there is an impact on limestone reserves. Alternatively, there is widespread availability of fly ash residue of pulverized coal produced in thermal plants. In the production of OPC and fly ash, there are 2 scenarios that are related to the environment: 1. The enormous quantity of carbon dioxide emitted in the atmosphere during cement manufacture, 2. The availability of fly ash massively disposed in landfills and posing an environmental threat.

As there is a pressing demand for environmentally friendly construction for the development of long-lasting and cost-effective building materials, cement concrete is replaced by materials which contain high percentage of silicon and alumina such as coconut jute fuel ash, Ground granulated blast furnace slag (GGBS), pulverised fuel ash, silica fume, which constitutes the geo-polymer concrete or green concrete.

Geopolymer concrete is current structure concrete that does not require cement as a binder since the fly ash commonly used may be activated by alkaline liquids to create geo-polymeric material. Several investigators have found that geopolymers have engineering proprieties similar or better than cement.

Although geo-polymer concrete is a new material as a substitute of ordinary or conventional concrete, but has its own drawbacks, such as a high financial risk of working with the new revolutionary material and a difficult task of understanding the properties of GPC due to the lack of a specific code of practice. Care should be taken before procuring the material and checking the structure to know the appropriateness of the chemicals to be used as source material for GPC.

Origin of Term Geopolymer

Davidovits was the first to bring the term "Geo-polymers" to the chemical community in the mid-1970s. "Geosynthetic" is the science of creating artificial rock with natural features at temperatures below 1000°C (hardness, longevity, and heat stability). Geopolymers were once thought to be mineral polymers formed by geochemistry or geo-synthetic. The cement was replaced with materials rich in silicon and alumina to form Geo-polymer Concrete.

Experimental investigation

Materials

- Fine and Coarse aggregates

Sand and gravel are inert mineral components that frame approximately 70-80% of the quantity of concrete. Coarse and fine aggregates mixed should become void-free and homogeneous. The grading of fine particles affects the workability of geo-polymer concrete. Coarse aggregates consisting of gravel of size 10-20 mm are obtained by pulverizing hard rock stones. The locally available fine aggregates of grading zone 2 are used. The physical parameters of gravel and fine aggregates(sand) were determined in accordance to the specifications laid down in IS 383: 2016.

- Fly Ash

It is a by-product of pulverized fuel ash or coal combustion that consists of fine particles that are blasted out of the boiler with the flue gases. The fly ash’s quantity and fineness employed in the activation process of geopolymer concrete affect concrete’s strength. Similarly, the higher the fineness, the better the workability and strength within a short heating time. The physical features of fly ash are tabulated in table 1.

Table 1: Its Physical properties

1.fineness	405m^2/kg
2 specific gravity	2.4

3 size and shape	40micon Spherical shaped
4 colour	Dark grey

The chemical components of fly ash are tabulated in table 2.

Table 2: Its Chemical composition

component	Percentage
SiO_2	49.46
Al_2O_3	29.71
Fe_2O_3	10.82
CaO	3.45
MgO	1.26
K_2O	0.53
Na_2O	0.33
TiO_2	1.76
P_2O_5	0.53
MnO_3	0.16
SO_3	0.28
LOI	1.46

- Ground Granulated Blast furnace Slag(GGBS)

  GGBS is a by-product of the iron-making blast furnaces, resulting in a granular product that is subsequently dried and processed into a fine powder. The physical characteristics of GGBS are tabulated in table 3.

Table 3 Its Physical features

2 specific gravity	2.88
3 particle shape	irregular
4 colour	Off white

The chemical characteristics of GGBS are tabulated in table 4.

Table 4 Its Chemical characteristics

component	Percentage
SiO_2	36.3
Al_2O_3	18.65
Fe_2O_3	0.84
Chloride content	0.010
MgO	6.8
K_2O	0.84
Na_2O	0.24

P2O5	0.18
MnO	0.13
SO3	0.08

- Alkaline solution

The catalytic system, which consisted of sodium hydroxide, sodium silicate, and distilled water, was mixed together about 24 hours before casting the specimens and stored to cool.

In the polymerization reaction, the alkaline solution is critical. It acts as an activator in the polymerization reaction between material rich in alumina and activators solution, which results in the creation of a geopolymer structural paste binder.

Sodium Silicate (Na2SiO3) in the market is in gel form and also in solid form. The ratio of Na_2SiO_3 and NaOH has a huge influence on the strength of geopolymer or green concrete. Generally, a ratio of 1 to 3 produces adequate results. In this study the ratio of 1.25 is used. To guarantee the user's safety, the very alkaline solution should be handled with caution.

- Water

  The potable water free from impurities and meet the standards as laid down in IS 456:2020 was used in preparing and curing of the geo-polymer concrete

Preliminary investigation

The design mix was prepared by referring the guidelines laid down in IS 10262:2019. The constant and variable parameters used in the current study have been described as below:

Constant parameters:

- Characteristic compressive strength of geopolymer concrete: 30MPa
- Low calcium class F Fly ash fineness: 430 m^2/kg
- Curing type: oven heat curing
- Water to geopolymer binder ratio:0.3
- Alkaline activators (Na_2SiO_3 and NaOH):
  Ratio Na_2SiO_3 to NaOH: 1.25
  Solution /fly ash: 0.45
- Curing time: 24hours

Variable parameters

- Concentration of NaOH: 12,14 and 16M
- Curing temperature:30^0C,60^0C and 90^0C.

- Naphthalene superplasticiser: 1, 1.5, 2, 3% of mass of fly ash.

The mix proportion prepared by laboratory trials has been displayed in table 5.

Table 5: Mix proportions

Materials	Fly ash	GGBS	Na2SiO3	NaOH	Sand	Gravel	Water
Proportion	0.9	0.1	0.2	0.25	1.35	2.4	0.27

Experimental results and discussion

Workability of fresh geopolymer concrete

Geo- polymer concrete has shown a stiff consistency in its fresh condition. To avoid this problem naphthalene sulphorate superplasticizer was used to increase the workability of geopolymer concrete. NaOH 14M specimens were prepared and cured at 90^0 in an oven for 24 hours. The experimental findings of mixes 19 to 26 are shown in figure 1.

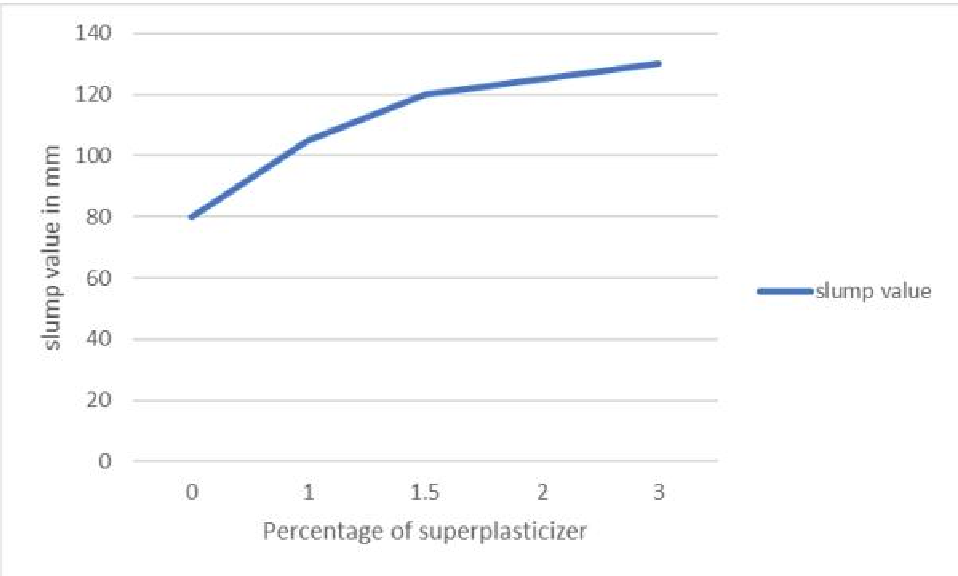


Figure1: Workability of geo-polymer concrete

From Fig 1,it can deduced that the workability of geo-polymer concrete improves with the increases of percentage of superplasticizer.

Tensile strength and Compressive strength of geo-polymer concrete

The different molarity used in geo-polymer concrete and the outcomes of the experiment for mechanical properties such as compressive tensile strength are given in table 6.

Table 6: Detail of mixtures

Mix No	NaOH Molarity	Age at test	Curing temperature	Average compressive strength(MPa)	Average tensile strength(MPa)	Additional data
1	8	7	60	20.45	2.5	
2	10	7	60	26	2.7	
3	8	28	60	39.1	3.5	
4	10	28	60	42.7	3.8	
5	12	7	30	28.85	2.8	
6	12	7	60	37.3	3.1	
7	12	7	90	39.1	3.5	
8	12	28	30	39.8	4.2	
9	12	28	60	55.5	5.45	
10	12	28	90	64	6	
11	14	7	30	30	3	
12	14	7	60	44	3.9	
13	14	7	90	46.5	4	
14	14	28	60	66.7	6.1	
15	14	28	90	68.3	6.3	
16	16	7	30	26	2.1	
17	16	7	60	36.5	3.8	
18	16	7	90	39	3.9	
19	14	7	90	45	4.3	
20	14	7	90	48.6	5	
21	14	7	90	47	4.8	
22	14	7	90	44.3	3.9	
23	14	28	90	67.8	6	Superplasticiser 1% slump value:110
24	14	28	90	68.05	6.1	Superplasticiser 1.5% slump value:135
25	14	28	90	67.9	5.9	Superplasticiser 2% slump value:140
26	14	28	90	64.9	5.1	Superplasticiser 3%slump value:160
27	16	28	30	38.5	4.1	
28	16	28	60	53	5.7	
29	16	28	90	62.7	5.9	

Compressive strength of geo-polymers concrete was determined by casting cubes of sizes 15*15*15cm.These tests were carried out using the compressive testing machine after attaining an age of 7 and 28 days of curing according to IS: 4031(part 6)- 1988 as shown in fig 2. Concrete cubes were cast in three layers in the moulds. The tamping rod compacts each layer thorough. The cubes were demoulded after 24 hours then put in an oven for heat curing at a different temperatures. The split tensile strength of geo-polymers concrete was determined by casting the concrete cylinders of size 15*30 cm and testing them after 7 and 28 days of curing as shown in figure 3.

Figure 2 Test set up and cube specimen detail for compressive strength

Figure 3 Test set up and cylinder specimen detail for tensile strength

Figures 4 and 5 illustrate the effect of NaOH molarity on compressive and split tensile strength of geo-polymer concrete.

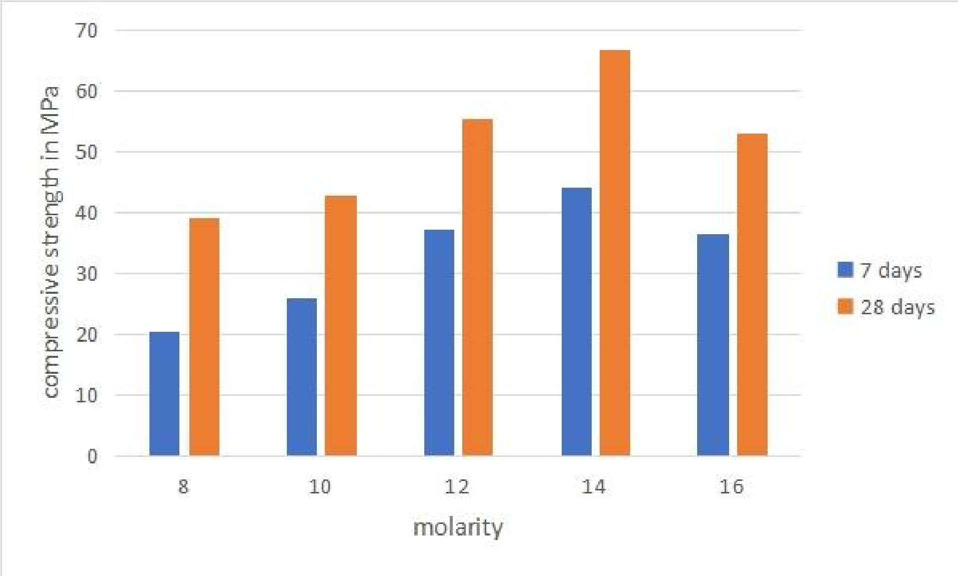


Figure 4: Effect of NaOH Molarity on Compressive strength of geo-polymer concrete

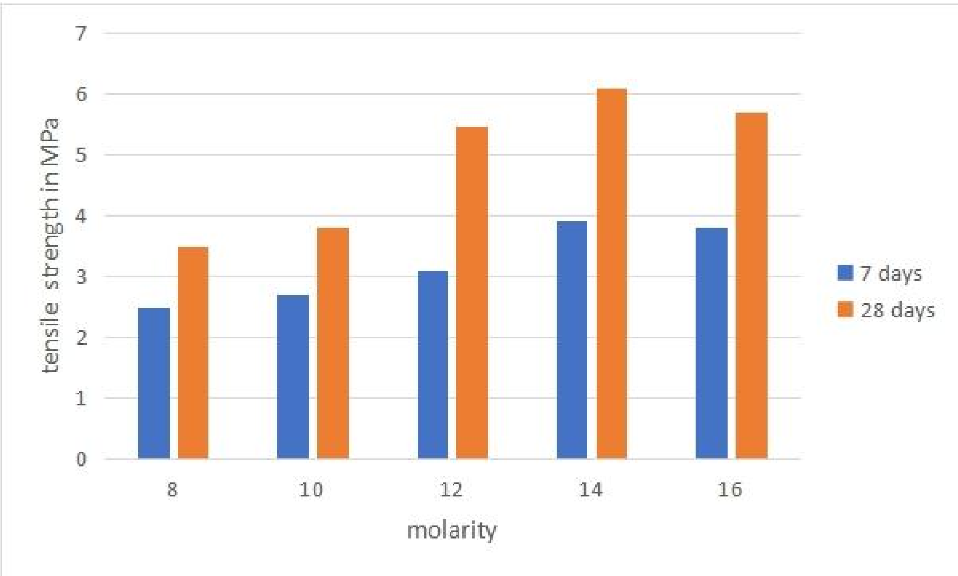
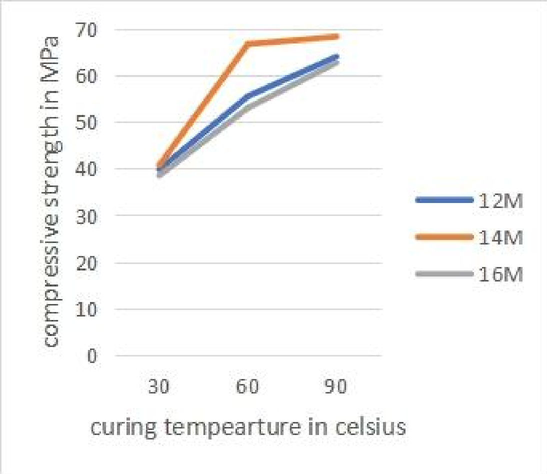


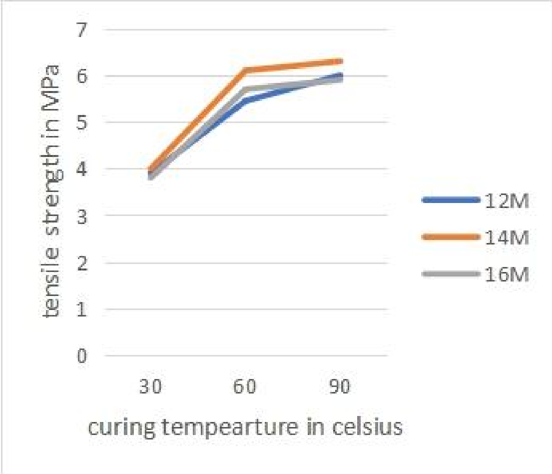
Figure 5: Impact of NaOH Molarity of Tensile strength of geopolymer concrete

The compressive strength after 7 and 28 days of testing range between 20.45-44 and 39.1-66.7 respectively. The mix with 14M NaOH gives the highest compressive and tensile strength of geopolymer concrete after both 7 and 28 days. For 16M NaOH the compressive and tensile strength decreases due to excess of Na^+ ions which affect polymerisation and lower strength.

Impact of curing temperature on compressive and tensile strength of geopolymer concrete



(A) Compressive strength



(B) Tensile strength

Figure 6: Impact of curing temperature after 28 days of curing on geo-polymer concrete

Fig 6 illustrates the effects of curing temperature on geopolymer strength. For each NaOH molarity, higher curing temperature results to higher compressive and tensile strength.

Young's modulus of elasticity

It is calculated using cylinder specimens 150mm in diameter and 300mm in height. The young's modulus of elasticity is calculated using a compressometer and a gauge. The test setup and cylinder specimen details for Young's modulus of elasticity was shown in figure 7.

Figure 7: Test set up and cylinder specimen detail for young's modulus of elasticity

Table 4: Value of Young's modulus of elasticity

Mixture	NaOH molarity	Age at test	Young's modulus of elasticity
10	12	90	30.8
15	14	90	32.7
29	16	90	32.5

The method used to find out the Young's modulus of elasticity of geopolymer concrete is the same as that used to determine the Young's modulus of elasticity of regular cement concrete. Its value is greater in NaOH 14M concrete, which is a clear proof of the increased compressive strength of geo-polymer concrete.

Conclusions

This current study described the effect of different parameters on various properties of Geo-polymer concrete such as workability, compressive strength, tensile strength and young's modulus of elasticity of Geo-polymer concrete. The following are the findings of the current research.

- A greater molar concentration of NaOH solution resulted in an improved tensile and compressive strength of fly ash-based geopolymer concrete.
- The insertion of a naphthalene sulphate superplasticizer up to roughly 3% of the mass of fly ash increases its workability while having no influence on hardened concrete compressive strength.
- The slump value of fresh Geo-polymer concrete is in the same range as that of ordinary concrete.
- The discontinuation of the usage of Portland Cement considerably decreases CO2 emissions, resulting in less environmental contamination.
- When compared to OPC, the 28-day strength values of geopolymer concrete are greater. This proves that Geopolymer concrete can be used in place of cement concrete.

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