INDIAN JOURNAL OF SCIENCE AND TECHNOLOGY

RESEARCH ARTICLE

OPEN ACCESS
Received: 23-07-2023
Accepted: 27-09-2023
Published: 28-10-2023

Citation: Kumar AS, Johnson C, Kumaran G (2023) Experimental Evaluation of the Mechanical Performance of Geo Polymer Concrete . Indian Journal of Science and Technology 16(40): 3530-3537. https://doi.org/10.17485/IJST/v16i40.1848

* **Corresponding author**.
siva_1667@yahoo.com

Funding: None

Competing Interests: None

Published By Indian Society for Education and Environment (iSee)

ISSN
Print: 0974-6846
Electronic: 0974-5645

Experimental Evaluation of the Mechanical Performance of Geo Polymer Concrete

A Sai Kumar[1]*, Christian Johnson[2], G Kumaran[3]

1 PhD Scholar, Department of Civil and structural Engineering Annamalai University, Chidambaram, India
2 Professor, Department of Civil Engineering, Erode Sengunthar Engineering College, Perundurai, India
3 Professor, Department of Civil and structural Engineering, Annamalai University, Chidambaram, India

Abstract

Objectives: To determine the important Mechanical properties and Elastic modulus of Geopolymer concrete (GPC). **Methods:** Four mix proportions of GPC using two molarities (12 and 14) of NaOH have been used to achieve M25 grade of GPC. Compressive strength, Tensile strength, Flexural strength and Young's Modulus (E_{GPC}) tests have been performed as per Codal provisions. **Findings:** The modulus of elasticity of GPC (E_{GPC}) for the four mixes has been determined experimentally and the average of four values was noted. With the help of this value,5000 random variables have been generated using Monte Carlo Technique and the average E_{GPC} (for 5000 values) has also been determined. Finally, it has been perceived that the elastic modulus of GPC is nearly equal to that of OPC in contrast to the previous studies.

Keywords: Compressive Strength; Geopolymer Concrete; Elastic Modulus; Molarity; Split Tensile Strength

1 Introduction

Universally, cement takes a vital part in the creation of the world. The major problem with OPC which is known as ordinary Portland cement is the excessive CO_2 liberation which is harmful to the society. It is well known that the acuity of the world is 'Green house emission'. Hence a thirst of searching new products as replacement for cement has been generated and thus in 1945, Joseph Davidovits discovered Geopolymer concrete (GPC) which is termed as Carbon less concrete. This new product consists of aluminosilicate materials (kaolinite, feldspar) and industrial by products (flyash, metallurgical slag) as a substitute of cement satisfying the pozzolanic properties [1–4]. To trigger these raw materials sodium hydroxide (NaOH), potassium hydroxide (KOH), sodium silicate (Na_2SiO_3) and potassium silicate (K_2SiO_3) are used as the main alkaline activators. These activators while reacting with silica, alumina and calcium form C-S-H gel. Consequently, the mechanical Characteristics of GPC are governed by different varying parameters such as Mix Proportion and Quality of the raw materials, Curing state (Oven Curing and Ambient curing), Alkaline activators involved [5–7].

The mechanical properties and elastic properties of GPC have been examined by some researchers in order to utilize it effectively[8–10]. It has been observed that the mechanical properties of GPC showed its preeminence than OPC in all aspects, whereas the modulus of elasticity showed lowliness when compared to OPC. It is well known that the stability of structures depends on modulus of elasticity (MoE) of concrete. Due to the different construction practices and maintenance system, the building components are found to be affected by the varying stresses and as a consequence the MoE and compressive strength get affected. Hence to offer an economic and stronger building, the examination of MoE becomes essential. MoE is highly dependent on the compressive strength of GPC. The inter relations between flexural strength, compressive strength, split tensile strength and modulus of elasticity mentioned in different national codes for OPC based concrete are also following nearly the same relations for alkali activated GPC with not much deviations. The compressive strength of GPC is also following the relation MoE as some function of f_{ck}, where Indian Standards use fck as cube compressive strength. For short term static modulus of elasticity of GPC, different researchers propose different equations but most of them propose MoE as a square root function of f_{ck} i.e. MoE = constant $\sqrt{f_{ck}}$.

A few literatures have been selected and compared with the present investigation to show the peculiarity of the present study. Thomas et al.,[9] concluded that the escalation in the elastic modulus of GPC was not at all noteworthy while increasing the compressive strength. It has been noted that in case of alkali activated Flyash, E_{GPC} varies linearly with f_{ck} whereas it remains constant in the case of activated GGBFS concrete over an array of f_{ck}. The relationship between E_{GPC} and f_{ck} has also been formed identical to the equations formed for OPC. In 2016, Noushini et al.,[11] created a mathematical equation for determining Elastic modulus of GPC and also concluded that E_{GPC} is lesser than that of E_{OPC} .Nath et al., 2017[12] examined that the elastic modulus of GPC was found below 30% when compared to OPC concrete. Bellum[13] investigated that Modulus of elasticity of GPC was found to be 15 to 28% lesser than that of OPC. An equation has been predicted for fly ash-GGBS based GPC at ambient curing for 28 days as E_{GPC}= 3282 $\sqrt{f_{ck}}$. Pradip Nath and Prabir Kumar Sarkar[14] stated the MoE of fly ash-based GPC replacing fly ash by 15% slag and 8% OPC as $3510\sqrt{f_{ck}}$. Likewise, Amjad et al[15] conveyed that 10 to 50% replacement of cement by fly ash yields a MoE of concrete (4300 to 4750) $\sqrt{f_{ck}}$. These lesser values might be due to the mixing proportions of alkaline activators and binders or curing conditions or testing methods.

The current study scrutinizes the mechanical properties of GPC of various mix combinations to achieve the M25 grade GPC and also targets the modulus of elasticity of the same. Regarding the elastic modulus of GPC, the previous researchers experimented a lesser value of E_{GPC} than E_{OPC} and allied to that, some equations have also been recommended. That proposal has been wrecked in the current study by noticing a hike in the elastic modulus of GPC for four different mix proportions and a new formula has been suggested to predict elastic modulus. Ambient curing for 28 days gives best results. The alkaline ratio (Sodium silicate and sodium hydroide) was kept as 2.5. Total binder is a combination of 70% Flyash and 30% GGBS. For good workability some percentage of water and super plasticizer were mixed (Table 4). Monte carlo simulation technique has been performed using the average of the elastic modulus (experiment value) obtained from the four different mix proportions to avoid the cumbersome experimental findings. A histogram has been drawn with the generated variables to understand the shape and distribution of data points and also to assess their fit.

2 Methodology

The materials involved in the preparation of GPC were described in the following sub headings and their properties have been tabulated from Tables 1, 2 and 3.

2.1 Fly Ash and GGBS

Fly ash was collected from the Mettur Thermal Power Station, Tamil Nadu, and GGBS was supplied by Navoday Science Pvt. Ltd.

2.2 Aggregate

Locally available crushed, angular shaped ≤20mm nominal sized coarse aggregate ratifying IS 383:1970 and M-Sand (fine aggregate-Zone II) approving IS 383:1970 were bought.

2.3 Alkaline Activator Solution

Sodium Silicate solution and Sodium Hydroxide pellets are easily available in markets (Naveen chemicals, Chennai). The alkaline activator is subjected to thorough mixing and kept for at least 24h before it comes to the usage. The ratio of Na_2SiO_3 to NaOH in terms of mass is 2.5. 12 M and 14 M solution were prepared by dissolving 480g and 560g of NaOH in one litre of

Table 1. Properties of Flyash and GGBS

Different Properties	Cement	Flyash	GGBS
Colour	grey	grey	Off white
Specific gravity	3.17	2.54	2.87
CaO	61.52	1	34.48
SiO2	20.37	65.6	30.61
Al2O3	4.31	28	16.24
Fe2O3	5.98	3	0.584
MgO	1.36	1	6.79
LOI	6.47	0.29	5.12
Tio2	-	0.5	-
SO3		0.2	1.85

Table 2. Properties of aggregates

Properties of aggregates	Fine aggregates	Coarse aggregates
Water absorbtion	1.5%	0.90%
Fineness modulus	2.81	7.16
Specific gravity	2.58	2.83

water respectively.

Table 3. Important Properties of chemicals involved in the preparation of GPC

Various Factors	Properties	
	(Sodium Hydroxide)	(Sodium Silicate)
Appearance	Solid	Liquid
Colour	White	Colourless
Odour	Odourless	Musty
pH	14	11
Melting Point	323 °C	1.088 °C
Boiling Point	1388 °C (1013.25 hPa)	102 °C Density Molecular Mass Solubility
Vapour Pressure	< 0.1 hPa (20 °C)	
Density.	2130 kg/m3	1.37 g/ml
Molecular Mass	40 g/mol	122.06 g/mol
Solubility	Soluble in water, ethanol, methanol and glycerol.	Insoluble in alcohol. Fully soluble in water.

2.4 Superplasticizer (SP)

Super plasticizer is used in the mix to increase the workability. CONPLAST SP 430 which has been supplied from Fosroc Chemicals, India, was used as a superplasticizer in the current study.

3 Results and Discussion

The Current study mainly focuses the important properties of GPC under ambient curing state. Four trial mixes of GPC 25 were adopted. According to IS 10262-2019 codal provisions, the mix proportions to achieve M25 grade of GPC have been prepared. The standard size of cylinder with 150mm diameter and 300mm height were cast for conducting elastic modulus Test. For the compression and tension tests 150mm x 150mm x 150mm cubes were cast. To carry out the flexural strength tests 150mm x 150mm 500 mm sized prisms were cast in the Structural Testing Laboratory, Annamalai University [16]. The four mixes of GPC M25 were shown in Table 4.

Table 4. Different mixes of GPC cube specimens

Trial Mix	M	FA	GGBS	Fine Agg	Coarse Agg	NaOH	Na_2SiO_3	W	SP%	Added Water
1	12	3.55	0.89	7.45	13.3	0.27	1.47	0.3	0.18	0.2
2	12	3.11	1.33	7.45	13.3	0.27	1.47	0.3	0.23	0.22
3	14	3.11	1.33	7.45	13.3	0.32	1.47	0.25	0.24	0.24
4	12	3.33	1.11	7.45	13.3	0.27	1.47	0.3	0.18	0.2

M-Molarity; FA-Fly Ash in Kg; W-Water in Kg; SP-Super plasticizer

3.1 Workability of the GPC Mix

GPC mix has been turned more cohesive and sticky due to the alkaline activator [4,8]. On increasing the percentage of GGBS above 30, it has been observed that the workability decreases due to the quicker polymerization. The workability of GPC in terms of Slump is shown in Table 5.

Table 5. Workability of GPC

Trial Mix	Slump value(mm)
1	120
2	115
3	100
4	125

3.2 Mass Density

According to ASTM C 642, the mass density of GPC has been determined as varying from 2450 to 2520 $kg.m^{-3}$. This value was found lesser than that of OPC and also it has been confirmed that the reason behind might be the poor specific gravities of Fly ash and GGBS.

3.3 Strength Tests

The GPC specimens have been tested [17,18] after a curing time of 28 days and various strengths have been tabulated in Table 6. Figure 1 presents the preparation stages of GPC specimens.

Fig 1. Mixing, placing and demoulding of concrete

Table 6. Strength Test Results of GPC

Trial Mix	Compressive strength	Split tensile strength	Flexural Strength
1	35.9	3	2.65
2	38.04	3.2	2.8
3	39.4	3.2	2.82
4	35	3	2.7

3.4 Modulus of elasticity of GPC Specimens

According to ASTM C469, the elastic modulus of GPC has been determined using the cylinder specimens. Modulus of elasticity of GPC is the ratio of stress applied on the concrete to the corresponding strain triggered. A compression testing machine of 2000 kN was used to conduct the laboratory Test. An extensometer was connected with the machine to observe the deformations for each and every incremental loadings. For several incremental loadings ,the corresponding deflections were observed until failure of the specimens. The same process have been applied for all the trial mixes and the results were taken from the graph drawn between the stress versus strain.

Fig 2. Elastic Modulus Test

Figure 2 presents the test setup for conducting Elastic Modulus Test and Table 7 gives the modulus of elasticity for all the trial mix specimens.

Table 7. Modulus of elasticity for the GPC mixes.

Trial Mix	ρ (kg/m^3)	ε_P	ε_U	α	E_I GPa	E_T GPa	E_S GPa
1	2450	0.0035	0.0043	0.51	24.85	20.5	20.9
2	2500	0.003	0.0040	0.7	25.6	21.5	21.9
3	2510	0.003	0.004	0.7	25.8	22.5	21.3
4	2460	0.0037	0.0042	0.53	24.6	23.3	21.5

Where, ρ is unit weight, f_{ck} is cylindrical compressive strength or Peak stress, ε_p is peak strain, ε_u is ultimate strain, E_i is initial modulus of elasticity, E_t is tangent modulus of elasticity, E_s is secant modulus or ultimate modulus of elasticity.α is Linear Coefficient of Curve (average of the ratio between each stress and the peak stress).

3.5 Monte Carlo simulation

In order to identify the uncertainties, Monte Carlo simulation (MCS) technique has been adopted. In the current study, 5000 random variables have been generated using MCS and the normal distribution becomes essential to create the variables which are nearer to the experimental data of the present study. Figure 3 depicts the normal distribution curve in the form of histogram of the generated variables. In this study the uncertainties associated with the Modulus of elasticity (E_{GPC}) were taken as random variable. Probability Density Function (PDF) and Cumulative Distribution Function (CDF) were used to demarcate the random variable in the form of a mathematical expression.

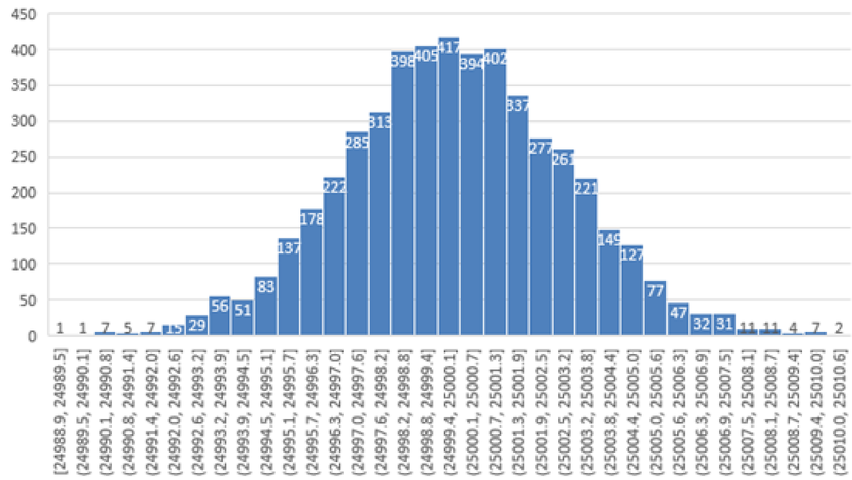

Fig 3. Histogram of generated variables

Some other important basic statistical parameters like Mean, Standard deviation, Coefficient of Variation and Bias are also required to describe the properties of the variables mathematically as given in Table 8. With the standard formulae these parameters were calculated.

Mean:

$$\mu_x = \frac{1}{n}\sum_{i-1}^{n} X_i \tag{1}$$

Where, n is number of observations, and Xi is the set of observations.

Standard deviation:

$$\sigma_x = \frac{\pi\sqrt{\left(\sum_{i-1}^{n} X_i^2\right) - n\mu_x^2}}{n-1} \tag{2}$$

Coefficient of Variation:

$$V_x = \frac{\sigma_x}{\mu_x} \tag{3}$$

The value CoV upto 0.05 is a realistic target for maximum problems

Bias:

$$\lambda_x = \frac{\mu_x}{X_n} \tag{4}$$

where, X_n is the nominal value of variable.

Table 8. Statistical properties of the Elastic Modulus of GPC

Number of generated values	Mean	Std Deviation	COV	Bias	Equation generated
5000	25200	3	0.025%	1	$E_C = 5040\sqrt{f_{CK}}$

Figure 4 shows the graph drawn between the randomly generated values of Elastic modulus and the elastic empirical constant. R^2 equals 1 confirming the fitness of the model. The equation proposed for the Elastic modulus of GPC is $E_{GPC} = 5040\sqrt{f_{CK}}$. The current study contravenes the proclamation given by Previous researchers and the comparison is shown in Table 9.

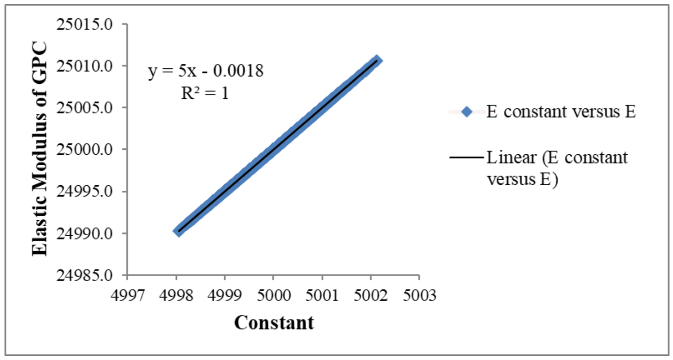

Fig 4. A graph drawn between the generated Elastic modulus of GPC and their corresponding Constants (MonteCarlo Technique)

Table 9. A Comparison between the Present and Past studies

S.No	Reference Number	Elastic Modulus (GPa)	Formula Suggested
1	[9]	10.589	$E = [4.26C^2 - 111.74C + 10365]*10^{-3}$ GPa
2	[19]	20.5	$E_{GPC} = 4100\sqrt{f_{CK}}$ MPa
3	[13]	13 to 20.1	$E_{GPC} = 3282\sqrt{f_{CK}}$ MPa
4	Current Study (2023)	25.2	$E_{GPC} = 5040\sqrt{f_{CK}}$ MPa

4 Conclusion

From the current study, GPC is considered as a wonderful replacement of OPC in all the aspects of sustainability with the required qualities such as higher strength, reuse of waste, cheeper binder materials, minimization of carbon and greenhouse gases and good frost resistance. However the properties should be thoroughly checked before put into bulk efficacy. Though so many researchers have provided a lot of information on the superior properties of GPC, the important property specifically Elastic modulus of GPC was found to be less in their works (Table 9) . The present study breaks that declaration and perceived a 2 to 3 times higher value of elastic modulus of GPC. To conclude this, four different mix proportions of GPC to achieve M25 grade of concrete have been prepared and the mechanical properties, elastic modulus have been tested as per the codal provisions. The proposed equations of the Elastic Modulus of GPC both experimentally and using simulation technique were found to be accurate due to its dependency on a large number of data. From the experimental data on fly ash-GGBS based GPC, the following conclusions are drawn:

1. Two molarities (12 and 14M) were used to prepare four mix proportions
2. An addition of 30% GGBS in the mix enhances the properties
3. The Trial mix 4 of GPC showed an optimum compressive strength (39.4Mpa), split tensile strength (3.2MPa) and flexural strength(2.82MPa) at ambient curing for 28 days.
4. The elastic modulus value is found to be 25 GPa which is closer to that of OPC.
5. A new Equation $E_{GPC} = 5040\sqrt{f_{CK}}$ MPa has been recommended to relate Modulus of elasticity and compressive strength.

Acknowledgement

This research was supported by Navoday science PVT Limited, Chennai “Research and Development of cement and cementitious materials” They have provided us GGBS required for the present research work at free of cost.

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