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Probabilistic modeling of geopolymer concrete using response surface methodology

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Abstract. Geopolymer Concrete is typically proportioned with activator solution leading to moderately high material cost. Such cost can be enduring in high value added applications especially when cost savings can be recognized in terms of reduction in size of the members. Proper material selection and mix proportioning can diminish the material cost. In the present investigation, a total of 27 mixes were arrived considering the mix parameters as liquid-binder ratio, slag content and sodium hydroxide concentration to study the mechanical properties of geopolymer concrete (GPC) mixes such as compressive strength, split tensile strength and flexural strength. The derived statistical Response Surface Methodology is beleaguered to develop cost effective GPC mixes. The estimated responses are not likely to contrast in linear mode with selected variables; a plan was selected to enable the model of any response in a quadratic manner. The results reveals that a fair correlation between the experimental and the predicted strengths.

Keywords: geopolymer concrete; slag; mechanical properties; response surface methodology; box-behnken design

1. Introduction

The utilization of various forms of waste to achieve innovative building material is an option for exploiting the huge amount of wastes which results every year. The cement industry is the major source of CO_2 emission to the atmosphere worldwide nearly 1. 8GT annually (Barker *et al.* 2009). This accounts for 7% of the total CO_2 emission (Deja *et al*. 2010) which will increase rapidly due to the increase in the cement production. Second only to China, India produces about 135 MMT per annum, this is almost 6% of the global cement production. Polymer concrete with additions persists to grow since in various circumstances by introducing fine materials in the mix, the properties can be enhanced and the cost can be reduced. Geopolymers are deemed to be a cluster of new alumino-silicate resources of composition and properties permitting their function in copious innovative tools. The prospect of utilizing them as a substitute for Portland cement appears to be the main momentous feature. Geopolymers can be generated from an extensive array of mineral compositions for instance like fly ash, blast furnace slag, etc. (Deventer *et al.* 2007, Kumar *et al.* 2010, Homwuttiwong *et al.* 2012). Most well-known alkaline solution employed in the geopolymer technology is the mixture of sodium hydroxide with sodium silicate or potassium hydroxide with potassium silicate (Kar *et al.* 2016). Compared with OPC, binders with alkali activated slag are in general reported to have enhanced resistance to sulfate attack (Rodriguez *et al.* 2008). Response Surface Methodology (RSM) is a significant statistical tool in the design of experiments to optimize a response which is influenced by several independent variables especially in the field of concrete technology (Yeh 2008, Kandasamy and Akila 2015, Khan *et al.* 2016). It explores the relationship between the response function and several variables and to verify the influence of the factors and their interaction under limited runs (Sugumaran *et al.* 2013). The concept and the technique of RSM have been widely utilized in various divisions of engineering.

2. Materials and methods

2.1 Materials

Ground Granulated Blast Furnace Slag (GGBFS), a derivative of iron with a specific gravity of 2.90, bulk density of 1231 kg/m^3 and specific surface area of 1.56 m^2/g has been taken as geopolymer source material. The chemical analysis of GGBFS has been carried out using XRF (Bruker S8 Tiger) and the percentage of chemicals present in the sample is detailed in Table 1.

From the chemical composition of GGBFS presented in Table 1, the basicity coefficient was found to be 0.98 (less than 1) thereby the GGBFS was categorized under acidic nature can be best suited as a starting substance for alkali activated slag binder. The ratio of CaO/SiO_2 is 1.18 (between 0.5 and 2.0) and Al_2O_3/SiO_2 is 0.56 (between 0.1 and 0.6) (David and Andi 2012) which makes GGBFS best suited as binder. The degree of hydration is mainly influenced by the hydration modulus, which was found to be 2.04 and should exceed 1.4 (Chang 2003).

Crushed granite stone aggregates of mixed size available

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Table 1 Chemical composition of OPC and GGBFS

Oxide	CaO	SiO_2	Al_2O_3	MgO	SO_3	Fe_2O_3	Na_2O	K_2O
GGBS	36.77	30.97	17.41	9.01	1.82	1.03	0.69	0.46

Table 2 Properties of fine and coarse aggregates

Properties	Fine aggregate	Coarse aggregate
Bulk density (kg/m^3)	1696	1485
Specific gravity	2.58	2.72
Moisture absorption (%)	1.37	0.77
Fineness modulus	2.56	6.97
Los Angeles Abrasion Value (%)	-	18.52
Aggregate Impact Value (%)	-	14.52
Aggregate Crushing Value (%)	-	27.74

Table 3 Properties of alkaline solution

Sodium Hydroxide		Sodium Silicate	
Appearance	Flakes	Appearance	Clear less viscous liquid
Sodium hydroxide	99.51 (% by mass)	Specific gravity	1.35
Sodium carbonate	0.35 (% by mass)	Mg_2O	9 %
Chlorides	0.05 (% by mass)	SiO_2	28 %
Sulphates	0.005 (% by mass)	Solids	35 to 40 %
Silicates	0.004 (% by mass)		
Iron	8 ppm		

in the vicinity was used as coarse aggregate and local river sand in saturated surface dry condition was used as fine aggregate and their properties are listed in Table 2.

Alkaline Activated Solution (AAS) used in the GPC mixes is a mixture of Sodium Hydroxide (NaOH) and Sodium Silicate (Na_2SiO_3) Solution and their properties are given in Table 3. Sodium hydroxide was available in the flakes form. NaOH solution was prepared by dissolving the calculated amount of flakes in distilled water for the required concentration. NaOH solution was prepared a day before casting during which it undergoes exothermic process, thus resulting in the reduction of the excess heat generated during its preparation. Then the Na_2SiO_3 solution was mixed the NaOH solution for the required ratio of AAS. The function of AAS is to liquefy the reactive component of source materials present in the slag and to afford a highly alkaline solution for condensation polymerization reaction.

2.2 Mix proportioning of GPC

With the density of fresh concrete as 2400 kg/m^3, the proportion of total aggregates was varied as 72, 75 and 78% of the whole mix by mass. A total of 27 mixes with a liquid-binder ratio of 0.45, 0.50 and 0.55, binder content of 350, 400 and 450 kg/m^3, Sodium hydroxide concentration of 10, 12 and 14 M were taken for this investigation, keeping the alkaline ratio constant at 2.0. The detailed mix proportioning of geopolymer concrete is detailed in Table 4. The mixes were classified under 3 categories with A: Liquid-binder ratio of 0.45, B: Liquid-binder ratio of 0.50 and C: Liquid-binder ratio of 0.55.

Table 4 Mix proportion of geopolymer concrete mixes

Mix No.	L/B ratio	Quantity in kg/m^3			
		Slag	Fine aggregate	Coarse aggregate	Activator solution
A1	0.45	350	450	1422	157.5
A2	0.45	400	432	1368	180
A3	0.45	450	415	1313	202.5
B1	0.50	350	450	1422	175
B2	0.50	400	432	1368	200
B3	0.50	450	415	1313	225
C1	0.55	350	450	1422	192.5
C2	0.55	400	432	1368	220
C3	0.55	450	415	1313	247.5

2.3 Methodology

2.3.1 Experimental investigation

The compressive strength, split tensile strength and flexural strength of the GPC mixes were examined for the above mixes and the tests were conducted as per the Indian Standards. Compressive strength was assessed with 150 mm×150 mm×150 mm cube specimens tested under Compression Testing Machine (CTM) of 3000 kN capacity. The split tensile strength was evaluated using 100 mm×200 mm cylindrical specimens tested under CTM. The flexural strength was examined with 500 mm×100 mm×100 mm prisms tested under Universal Testing Machine (UTM) of 1000 kN capacity. An average of 3 specimens were tested after 28 days of ambient curing condition as curing under elevated temperature show no momentous increase in the strength after 28 days (Davidovits 1994).

Fig. 1 shows the specimens under loading conditions.

2.3.2 Characterization

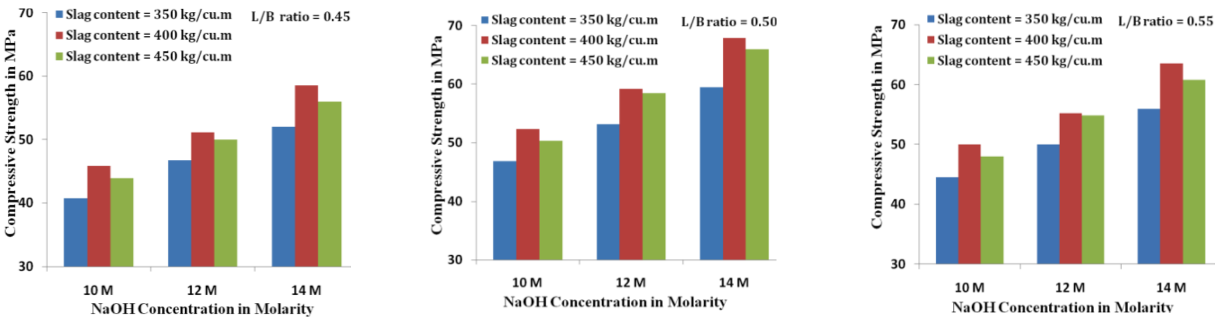
The morphology of the geopolymer sample was studied using X-ray diffraction (D_8 Focus, Bruker). The samples were finely powdered and the analysis was done at an accelerating voltage of 40 kV under an alternating current of 40 mA subjected to CuKα radiation with 2Θ step size ranges from 20^o to 80^o.

2.3.3 Statistical assessment using response surface methodology

Box-Behnken design was executed to examine the effect of three mix parameters namely, liquid-binder ratio, slag content (kg/m^3) and sodium hydroxide concentration (molar) on the mechanical properties of Geopolymer concrete. The non-linear model analysis of variance (NLMA) is a significant statistical analysis to compute the governance of a control factor by reducing the error variance. The independent variables were liquid-binder ratio (X_1), slag content (X_2) and Sodium hydroxide concentration (X_3); and the calculated response were the compressive strength (Y_1), split tensile strength (Y_2) and flexural strength (Y_3). The response surface can be

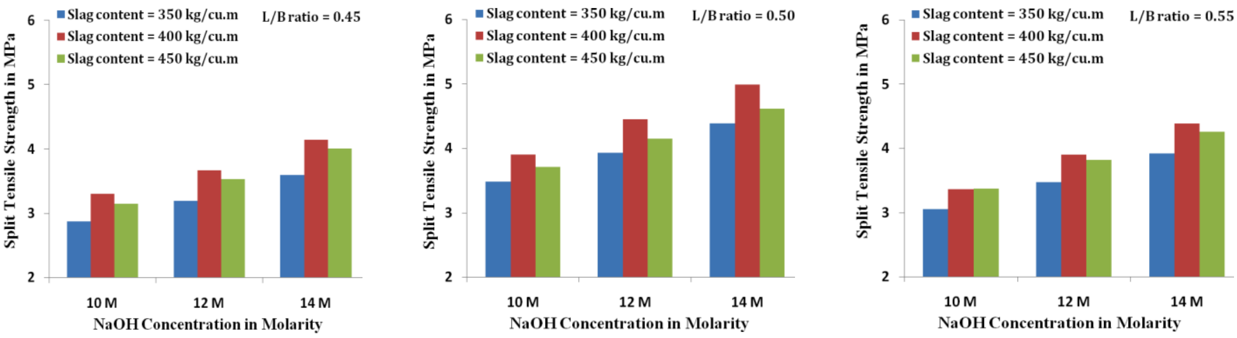
(a) Compressive strength (b) Split tensile strength (c) Flexural strength

Fig. 1 Specimens split tensile strength results of the GPC mixes



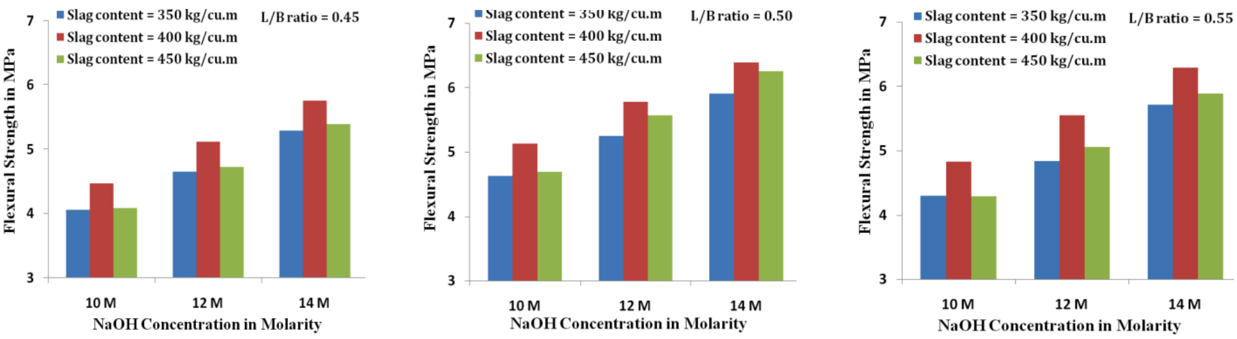
(a) L/B ratio=0.45 (b) L/B ratio=0.50 (c) L/B ratio=0.55

Fig. 2 Compressive strength results of the GPC mixes



(a) L/B ratio=0.45 (b) L/B ratio=0.50 (c) L/B ratio=0.55

Fig. 3 Split tensile strength results of the GPC mixes



(a) L/B ratio=0.45 (b) L/B ratio=0.50 (c) L/B ratio=0.55

Fig. 4 Flexural strength results of the GPC mixes

expressed in the form as below

$$Y = f(X_1, X_2, X_3) \quad (1)$$

In Box-Behnken design, three distinct stages were employed for independent variables and 15 runs including three central points are needed as given in Table 5. The statistical analysis was done by using Minitab 16 and the medium variable, x_i was coded as follows

$$x_i = (X_i - X_o)/\Delta X \quad (2)$$

Table 5 Levels of variables chosen for the experimental design

Variables	Minimum	Maximum
X_1: liquid-binder ratio	0.45	0.55
X_2: slag content (kg/m^3)	350	450
X_3: NaOH concentration (molar)	10	14

where x_i=coded variable; X_i=process variable; ΔX=change in un-coded value of a variable.

A second order model (Gunaraj and Murugan 1999), as declared in Eq. (3), was assumed to elucidate the correlation between the response function and the mix variables as it explains the variation in the mechanical properties of concrete (Bektas and Bektas 2014).

$$y = k_o + \sum k_i x_i + \sum k_{ii} x_i^2 + \sum\sum k_{ij} x_i x_j \quad (3)$$

where, y=required response variable; k_o, k_i, k_j, k_{ii}, k_{ij}=regression coefficients.

The capability of the arrived equation was detected by the coefficient of determination R^2. The p-values of the assigned experimental parameters show their impact on the response. The values ≤0.05 were deemed to have a momentous effect on the response function.

3. Results and discussions

3.1 Mechanical properties of geopolymer concrete

Figs. 2-4 illustrates the compressive strength, split tensile strength and flexural strength results of the GPC mixes at different liquid-binder ratios (0.45, 0.50 & 0.55) respectively. It is distinguished that the Geopolymer concrete with slag as binder reviewed here stated with compressive strength of above 40 MPa, permitting this material to be classified as High Performance Concrete (HPC). This high strength is credited to the physical and structural distinctiveness of the binders produced in these systems.

Fig. 2 illustrates the variation in the compressive strength of the GPC mixes for L/B ratio of 0.45, 0.50 and 0.55. The compressive strength values were observed to be in the range of 40.76 MPa to 67.85 MPa. Similarly, the split tensile strength and flexural strength results of the GPC mixes are illustrated in Figs. 3 and 4 respectively. The split tensile and flexural strength results were found to be in the range of 2.87 MPa to 4.99 MPa and 4.06 MPa to 6.39 MPa respectively. The variation in the mechanical properties with the design parameters are explained subsequently.

3.1.1 Effect of liquid-binder ratio on strength properties of GPC mixes

Increase in the alkaline liquid content reduces the strength while increase in the workability and setting time of the mixes. The compressive strength increases up to 15.31% with the increase in the liquid-binder ratio of 0.45 to 0.50 and then drops subsequently by 5.85% at 0.55. Similarly, in the case of the split tensile strength, the strength increases up to 19.70% from 0.45 to 0.50 and drops by 10.88% at 0.55. The flexural strength also shows a similar behavior where the strength increases on an average by 14.02% from 0.45 to 0.50 and drops by 5.89% at 0.55. The significant reduction in the strength of GPC mixes with excessive alkali activator (L/B=0.55) was asserted to be due to the dissolved Si and Al precipitation at the early phases prior to the polycondensation process initiation, which results in the development of cracks on the GGBFS particles (Sukmak *et al.* 2013). Increase in the liquid content leads to the reduction in the binder thereby improving the pore size resulting in the reduction of the strength development as well as excess liquid content hampered the polymerization process and promotes the poorly polymerized products (Ruiz-Santaquiteria *et al.* 2012).

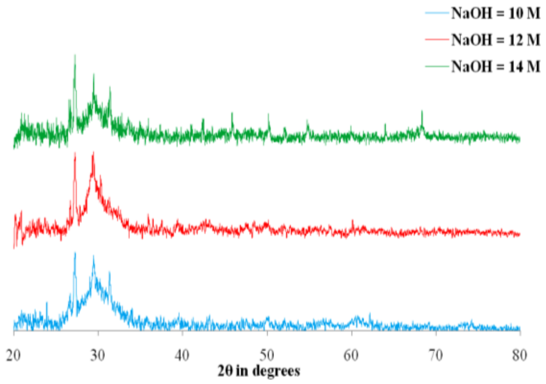


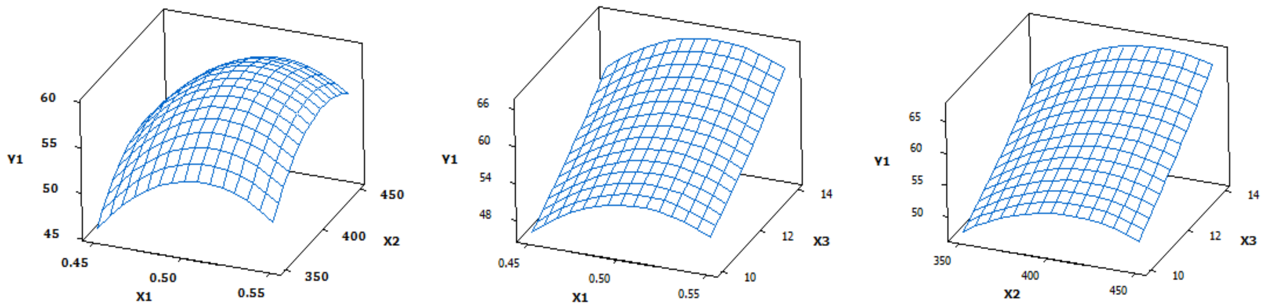
Fig. 5 XRD diffractograms of GPC mixes for various NaOH concentrations

3.1.2 Effect of GGBFS content on strength properties of GPC mixes

The use of high calcined source material as binder was stated to improve the microstructure of the geopolymer matrix resulting in high strength (Jaarsveld *et al.* 2002). The reaction between GGBFS and alkaline solution is an exothermal process and the generated heat which promotes the geopolymerization process. GGBFS contains higher CaO content and consequently, it is a good impending resource of soluble Ca in the mixture. The amount of soluble Ca depends on the GGBFS volume present in the mix and this has direct consequence on the compressive strength (Yusuf *et al.* 2014). Thus the increase in the slag content led to high compressive strength results. Similar observation was made in the present investigation with an increase in the compressive strength results was found to be on an average by 11.97% from GGBFS content of 350 to 400 kg/m^3 and drops up to 3.04% when increase to 450 kg/m^3. The observations were found to be similar in the case of split tensile and flexural strength results, where the strength increases by 13.21% and 10.56% respectively with an increase in the GGBFS content of 350 to 400 kg/m^3 and drops up to 3.92% and 7.08% when increase to 450 kg/m^3.

3.1.3 Effect of sodium hydroxide concentration on strength properties of GPC mixes

The concentration of sodium hydroxide considerably influences the compressive strength of geopolymers in their synthesis. The sodium hydroxide concentration on the



(a) L/B ratio vs slag content (b) L/B ratio vs NaOH concentration (c) Slag content vs NaOH concentration

Fig. 6 Interaction behaviour of variables in the determination of compressive strength

Table 6 Regression model for the determination of compressive strength in box-behnken design

Term	Coef	SE Coef	T	P
Constant	58.62	0.26	221.63	0
L/B Ratio	2.23	0.16	13.81	0
Slag Content	2.33	0.16	14.43	0
NaOH Concentration	6.79	0.16	41.94	0
L/B Ratio*L/B Ratio	-4.78	0.23	-20.07	0
Slag Content*Slag Content	-3.61	0.23	-15.18	0
NaOH Concentration*NaOH Concentration	0.63	0.23	2.66	0.045
L/B Ratio*Slag Content	0.23	0.22	0.98	0.371
L/B Ratio*NaOH Concentration	0.18	0.22	0.79	0.468
Slag Content*NaOH Concentration	0.76	0.22	3.31	0.021

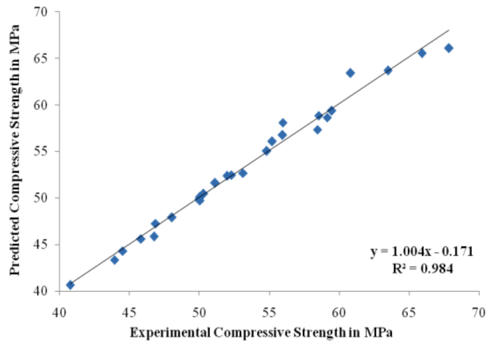


Fig. 7 Predicted compressive strengths through RSM for geopolymer mixes

aqueous phase of the geopolymeric system acts on the bonding of solid particles in the final structure as well as on the dissolution process. The utilization of high concentration sodium hydroxide solution increases the dissolution of the solid materials and the geopolymerization process resulting in higher compressive strength and mainly due to the higher degree of leaching of silica and alumina (Somna *et al.* 2011). Sodium hydroxide concentration on aqueous phases increases the compressive strength progressively up to 13.27% for an increase in the concentration of 10M to 12M; and an increase in the strength of 12.76% from 12M to 14M. This is in agreement with the results illustrated in (Alonso and Palomo 2001, Lee and Deventer 2002, Al Bakri *et al.* 2011, Parthiban and Saravana Raja Mohan 2014). In the case of split tensile strength, the strength increases 12.95% and 12.35% for an increase in the NaOH concentration from 10M to 12M and 12M to 14M respectively. For flexural strength these variations were observed to be 15% from 10M to 12M and a further increase of 13.75% from 12M to 14M. This is in agreement with the results illustrated by (Alonso and Palomo 2001, Lee and Van Deventer 2002). However, Hardjito *et al.* (2008) have reported that alkaline concentration was proportionate to the compressive strength of Geopolymer mortar. As the breakdown of aluminosilicate bonds is one of the fundamental strides of geopolymerization process, higher concentration of alkali leads to enhanced breakdown. The superior solvency of the aluminosilicate bond was observed with the increase in the NaOH concentration resulting in improved compressive strength (Khale and Chaudhary 2007, Bondar *et al.* 2011).

3.2 Characterization

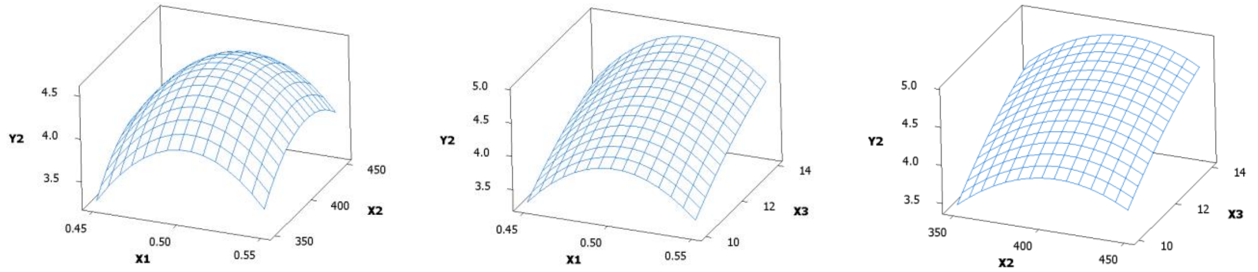
Fig. 5 shows the XRD pattern of powdered geopolymer mixes for NaOH concentration of 10M, 12M and 14M. The hump after 20^{o} indicates the formation of alumino-silicate reaction products. The increase in the NaOH concentration increases the intensity of peak with reduced width. This may be due to the increased dissolution of aluminosilicate source material at higher NaOH concentration due to the higher amount of heat evolved at higher concentration leads to higher strength (Rowles and O'Connor 2003) as well as reduces the formation of cracks (Xu and Deventer 2002).

3.3 Statistical assessment of the test results

The optimization of the experimental variables was done by using Box-Behnken statistical method. The analysis was executed at 0.05 significance level to spot the statistical impact of experimental constraints such as liquid-binder ratio (X_1), slag content (X_2) and Sodium hydroxide concentration (X_3) on the mechanical properties of GPC mixes and the experimental results are detailed in Table 3. In this analysis, the measured responses compressive strength (Y_1), split tensile strength (Y_2) and flexural strength (Y_3) was allotted as the dependent variables and the experimental parameters were preferred as independent variables.

The relationship selected being a second order non-linear polynomial equation and can be expressed as

$$Y_i=k_0+k_1X_1+k_2X_2+k_3X_3+k_4X_1^2+k_5X_2^2+k_6X_3^2+ k_7X_1X_2+k_8X_1X_3+k_9X_2X_3 \quad (4)$$



(a) L/B ratio vs slag content (b) L/B ratio vs NaOH concentration (c) Slag content vs NaOH concentration

Fig. 8 Interaction behaviour of variables in the determination of split tensile strength

Table 7 Regression model for the determination of split tensile strength in box-behnken design

Term	Coef	SE Coef	T	P
Constant	4.53	0.04	119.44	0
L/B Ratio	0.11	0.023	4.73	0.005
Slag Content	0.14	0.02	6.19	0.002
NaOH Concentration	0.46	0.02	19.86	0
L/B Ratio*L/B Ratio	-0.64	0.03	-18.72	0
Slag Content*Slag Content	-0.38	0.03	-11.33	0
NaOH Concentration*NaOH Concentration	-0.09	0.03	-2.70	0.042
L/B Ratio*Slag Content	0.002	0.03	0.07	0.942
L/B Ratio*NaOH Concentration	0.04	0.03	1.44	0.208
Slag Content*NaOH Concentration	0	0.03	0	1

In the above equation k_1, k_2,…., k_{14} are the coefficients for the measured response functions and are computed by Non Linear Regression Analysis was performed for the compressive strength using MiniTab16 software and are listed in Table 6.

From the Table 6, it has been observed that the linear and the square terms have significant influence on the compressive strength of the GPC mixes as their p-values are less than 0.05, whereas the interaction between L/B ratio and slag content, L/B ratio and NaOH concentration & slag content and NaOH concentration are statistically not significant to assess the compressive strength as their p-values are greater than 0.05 at 95% significant level.

The competence of the model was further checked using ANOVA by without eliminating the insignificant parameters and the values of the regression were substituted in Eq. (5) to predict the compressive strength of GPC mixes.

$$Y_1=-645.6+1901.9X_1+1.1X_2-4.4X_3-1914.8X_1^2-0.001X_2^2+0.2X_3^2+0.1X_1X_2+1.8X_1X_3+0.01X_2X_3 \quad (5)$$

The above equation was solved by using inverse matrix method to obtain the maximum response function. The influence of the mix variables on the compressive strength of the geopolymer mixes are illustrated in Fig. 5 and the relation between the experimental values of the compressive strength with that of the RSM is shown in Fig. 7. The predicted values were found to be statistically significant in predicting the compressive strength.

The regression analysis for the determination of split tensile strength of the GPC mixes has been carried out and

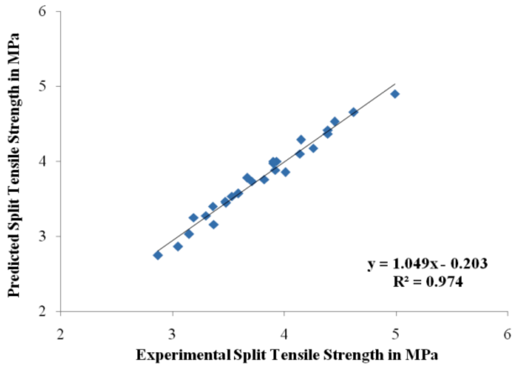


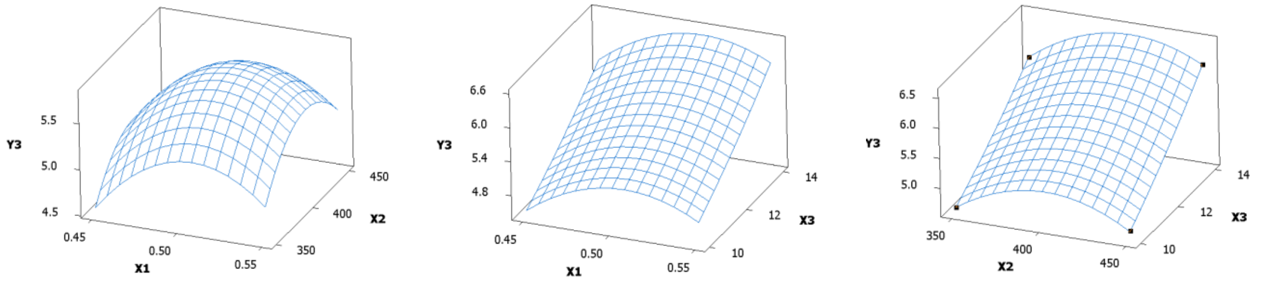
Fig. 9 Predicted split tensile strengths through RSM for geopolymer mixes

the resulting model is detailed in Table 7. Similar to the compressive strength results, the split tensile strength results also has a significant influence by the linear and the square terms as their p-values are less than 0.05, whereas the interaction between L/B ratio and slag content, L/B ratio and NaOH concentration & slag content and NaOH concentration are statistically not significant to assess the split tensile strength as their p-values are greater than 0.05 at 95% significant level. The competence of the model was further checked using ANOVA by without eliminating the insignificant parameters and the values of the regression were substituted in Eq. (6) to predict the split tensile strength of GPC mixes

$$Y_2=-89.6+252.1X_1+0.1X_2+0.5X_3-256X_1^2-1.6\text{x}10^{-4}X_2^2-0.02X_3^2+0.01X_1X_2+0.5X_1X_3+5.7\text{x}10^{-19}X_2X_3 \quad (6)$$

The above equation was solved by using inverse matrix method to obtain the maximum response function. The influence of the mix variables on the split tensile strength of the geopolymer mixes are illustrated in Fig. 8 and the relation between the experimental values of the split tensile strength with that of the RSM results is shown in Fig. 9. The predicted values were found to be statistically significant in predicting the split tensile strength.

The regression analysis for the determination of flexural strength of the GPC mixes has been carried out and the resulting model is detailed in Table 8. Similar to the compressive and split tensile strength results, the flexural strength results also has a significant influence by the linear and the square terms as their p-values are less than 0.05, whereas the interaction between L/B ratio and slag content, L/B ratio and NaOH concentration & slag content and NaOH concentration are statistically not significant to



(a) L/B ratio vs slag content (b) L/B ratio vs NaOH concentration (c) Slag content vs NaOH concentration

Fig. 10 Interaction behaviour of variables in the determination of flexural strength

Table 8 Regression model for the determination of flexural strength in box-behnken design

Term	Coef	SE Coef	T	P
Constant	5.77	0.02	226.25	0
L/B Ratio	0.18	0.01	11.67	0
Slag Content	0.09	0.01	6.24	0.002
NaOH Concentration	0.70	0.01	45.11	0
L/B Ratio*L/B Ratio	-0.49	0.02	-21.59	0
Slag Content*Slag Content	-0.46	0.02	-20.28	0
NaOH Concentration*NaOH Concentration	0.06	0.02	2.75	0.04
L/B Ratio*Slag Content	0.03	0.02	1.35	0.233
L/B Ratio*NaOH Concentration	0.04	0.02	1.81	0.13
Slag Content*NaOH Concentration	0.07	0.02	3.16	0.025

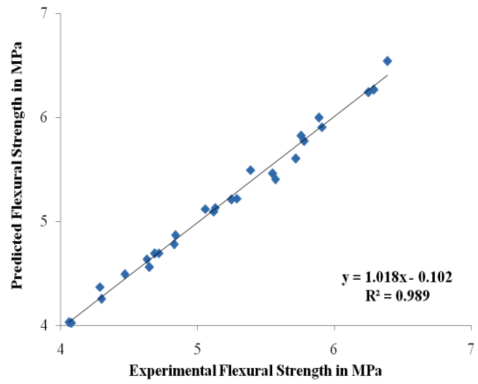


Fig. 11 Predicted flexural strengths through RSM for geopolymer mixes

Table 9 Coefficients of determinations for the responses examined

Response	Compressive strength	Split tensile strength	Flexural strength
R^2	99.82	99.45	99.84
R^2 predicted	97.99	93.39	98.19
R^2 adjusted	99.50	98.46	99.55

assess the flexural strength as their p-values are greater than 0.05 at 95% significant level.

The competence of the model was further checked using ANOVA by without eliminating the insignificant parameters and the values of the regression were substituted in Eq. (7) to predict the flexural strength of GPC mixes.

$$Y_3=-70.2+192.7X_1+0.1X_2-0.5X_3-198.7X_1^2-1.9\text{x}10^{-4}X_2^2+ 0.02X_3^2+0.01X_1X_2+0.4X_1X_3+7\text{x}10^{-4}X_2X_3 \quad (7)$$

The above equation was solved by using inverse matrix method to obtain the maximum response function. The influence of the mix variables on the flexural strength of the geopolymer mixes are illustrated in Fig. 10 and the relation between the experimental values of the flexural strength with that of the RSM results is shown in Fig. 11. The predicted values were found to be statistically significant in predicting the flexural strength.

The estimated coefficients of determinations for the responses are detailed in Table 9. High R^2 values shows that the design represents a fair degree of correlation between the mix variables and the response function. This also infers that the response surface model fits to the observed values, as their R^2 values are near to unity and shows a good prophecy for the determination of strength properties in geopolymer concrete.

4. Conclusions

The effect of the mix parameters (liquid-binder ratio, slag content and NaOH concentration) were investigated on the mechanical properties (compressive strength, split tensile strength and flexural strength) of slag based geopolymer concrete were investigated experimentally and a statistical prediction was done for the experimental results by using response surface methodology at three levels according to Box-Behnken design. The main findings of the study are as follows:

• The mechanical properties of the GPC mix increases with the increase in the liquid-binder ratio from 0.45 to 0.50 and decreases from 0.50 to 0.55.

• The mechanical properties also increase with the increase in the slag content from 350 kg/m^3 to 400 kg/m^3 and a slight reduction in the strength was observed at 450 kg/m^3.

• The mechanical properties of the GPC mix increases with the increase in the NaOH concentration due to the improved microstructure at higher NaOH concentration.

• The microstructure of the geopolymer product of the optimized mix reveals a semi-crystalline pattern.

• The linear and square terms of the regression model were found to have a significant contribution in the prediction of mechanical properties of GPC mixes, and no such significant contribution was made by the interaction models.

• High R^2 values indicate that the response surface models correlates with the experimental results and shows a good interpretation in the determination of mechanical properties of the geopolymer mixes.

• The results indicate that the RSM based on Box-Behnken method is suitable in predicting the mechanical properties of GPC mixes.

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