International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 3 Issue 9, September- 2014

Study of Mechanical Properties of Geopolymer Concrete Reinforced with Steel Fiber

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Abstract- **Concrete industry is the largest user of natural resources in the world and ordinary Portland cement production is the second only to the automobile as the major generator of carbon dioxide, which polluted the atmosphere. Also climate change due to global warming has become a major issue. Geopolymer concrete is an innovative construction material which shall be produced by the chemical action of inorganic molecules. In terms of reducing the global warming, the geopolymer could reduce the CO_2 emission to the atmosphere caused by cement and aggregate industries by about 80%. Fly ash is rich in silica and alumina reacts with alkaline solution produced aluminosilicate gel that acted as the binding material for the concrete. It is an excellent alternative construction material to the existing plain cement concrete. Geopolymer concrete is a type of amorphous alumino-silicate cementitious material. Geopolymer can be polymerized by polycondensation reaction of geopolymeric precursor and alkali polysilicates. This study focuses on the compressive strength and split tensile strength of geopolymer concrete reinforced with steel fiber.**

Key words- Geopolymer concrete; Fly ash concrete; Alkaline activator

I. INTRODUCTION

The term geopolymer was first used by Davidovits to alkali aluminosilicate binders formed by the alkali silicate activation of aluminosilicate materials as an alternative binder to the portland cement. Geopolymer concrete is a type of amorphous alumino-silicate cementitious material. Geopolymer can be polymerized by polycondensation reaction of geopolymeric precursor and alkali polysilicates. Geopolymer results from the reaction of a source material that is rich in silica and alumina with alkaline liquid. The polymerization process involves a substantially fast chemical reaction under alkaline condition on Si-Al minerals that result in a three dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds. Alumino-silicates oxides react with alkali polysilicates yielding polymeric Si – O – Al bonds. Polysilicates are generally sodium or potassium silicate supplied by chemical industry.

II. SCOPE

Study of literatures reveals that limited studies have been done in the study of geopolymer using steel fibers. The study involves finding the compressive strength and split tensile strength of geopolymer concrete by varying the Fly ash to chemical ratio (0.3, 0.35, 0.4), percentage of steel fiber (0, 0.5, 1) and temperature of curing: 28°C, 60°C, 90°C.

III. MATERIALS AND METHODOLOGY

Low-calcium (ASTM Class F) fly-ash is preferred as a source material than high calcium (ASTM Class C) fly-ash. The presence of calcium in high amount may interfere with the polymerization process. Fine aggregate used is M sand. Coarse aggregates of size 20mm and 12.5mm are used in the study in the ratio 60:40 and combinations of sodium hydroxide and sodium silicate is used as alkali activator. The physical and chemical properties of each ingredient has considerable role in the desirable properties of concrete like strength and workability. Fly ash used in the study is having specific gravity 2.1. Steel fiber used in the study has a length of 60mm.

A. Box Behnken Design

A Box-Behnken experiment is an example of Response Surface Methodology (RSM). Response surface methodology (RSM), which is based on factorial design, is a mathematical and statistical technique for designing experiments, fitting models, and determining the optimal operating conditions for a target response. Box–Behnken designs are experimental designs for response surface methodology, devised by George E.P.Box and Donald Behnken in 1960. Generally, a large number of specimens are required to study the properties of geopolymer concrete with three variables i.e., fly ash to alkaline liquids ratio, steel fiber percentage and temperature of curing. For that purpose, Box-Behnken design with three variable and three-level factors to reduce the numbers of specimen is adopted. Three control factors used in this experimental work are fly ash to alkaline liquids ratio, percentage of steel fiber and temperature of curing. In this design the treatment combinations are at the midpoints of the edges of the process space and at the center. FIGURE I show the Box Behnken for three factors.

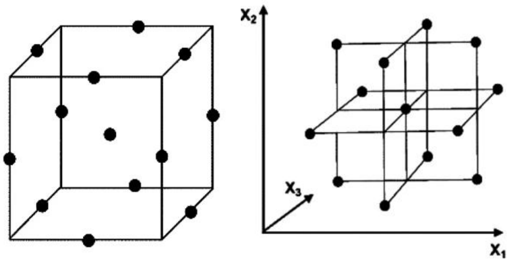

FIGURE I. Box Behnken Design for Three Factors

The model is designed as given in the equation 3.1

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \beta_{33} x_3^2 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{23} x_2 x_3 \quad \text{------ 3.1}$$

Where y is the predicted response, β_0 is model constant; x_1, x_2 and x_3 independent variables; β_1, β_2 and β_3 are linear coefficients; β_{12}, β_{13} and β_{23} are cross product coefficients and β_{11}, β_{22} and β_{33} are the quadratic coefficients.

B. Casting

The molarity of NaOH solution used in this study is 10 molar. The sodium silicate solution and the sodium hydroxide solution were mixed together at least one day prior casting. In preparation of NaOH solution, 400gm of NaOH pellets were dissolved in one litre of water in a volumetric flask for getting 10 molar solution. Pan mixer was used for mixing. The compressive strength and the workability of geopolymer concrete are influenced by the proportions and properties of the constituent materials that make the geopolymer paste.

C. Curing

The specimens were kept at room temperature for 3 days (rest period) and after that demoulded and placed in the hot air oven for 24 hours. The specimens were cured in hot air oven for 24 hours at 60°C and 90°C according to the study. Heat-curing substantially assists the chemical reaction that occurs in the geopolymer paste. Both curing time and curing temperature influence the strength of geopolymer concrete. The ambient curing specimens were kept at room temperature and demoulded after 3 days.

***C.** Quantity of Materials Required in 1 m^3 of Concrete*

Several mix designs were proposed for geopolymer concrete. The mix design for the investigation is adopted from the journal "optimum mix for geopolymer concrete" [4]. Quantity of materials required in 1 m^3 of concrete is shown in the TABLE I.

TABLE I

QUANTITY OF MATERIAL REQUIRED IN 1M^{3}OF CONCRETE

Percentage of steel fiber (%)	**Ratio of fly ash to alkaline liquids**	**Fly ash (kg)**	**Fine aggregate (kg)**	**Coarse aggregate (kg)**	**Alkaline liquids (kg)**		**Steel fiber (kg)**	**Designation**
					NaOH	**Na_2SiO_3**		
0	0.3	467	612	1346	40	100	0	$R_{0.3}F_0$
	.35	400	612	1346	40	100	0	$R_{0.35}F_0$
	0.4	350	612	1346	40	100	0	$R_{0.4}F_0$
0.5	0.3	464	608	1339	39	99	39.25	$R_{0.3}F_{0.5}$
	0.35	398	608	1339	39	99	39.25	$R_{0.3}5F_{0.5}$
	0.4	348	608	1339	39	99	39.25	$R_{0.35}F_{0.5}$
1	0.3	462	605	1332	38	98	78.5	$R_{0.3}F_1$
	0.35	396	605	1332	38	98	78.5	$R_{0.35}F_1$
	0.4	346	605	1332	38	98	78.5	$R_{0.4}F_1$

IV. RESULTS AND DISCUSSIONS

Compressive strength and Split tensile Strength of specimen are tabulated in the TABLE II.

TABLE II.
COMPRESSIVE STRENGTH AND SPLIT TENSILE STRENGTH OF SPECIMEN

Designation	Temperature °C	Compressive strength N/mm^2	Split tensile strength N/mm^2
$R_{0.3}F_0$	60	24	2.0
$R_{0.35}F_0$	27	15.5	1.7
$R_{0.35}F_0$	90	26	2.4
$R_{0.4}F_0$	60	25	2.3
$R_{0.3}F_{0.5}$	27	15.7	2.1
$R_{0.3}F_{0.5}$	90	25	3.0
$R_{0.35}F_{0.5}$	60	26.2	3.1
$R_{0.4}F_{0.5}$	27	17.8	2.3
$R_{0.4}F_{0.5}$	90	27	3.4
$R_{0.3}F_1$	60	24.6	3.3
$R_{0.35}F_1$	27	18	2.9
$R_{0.35}F_1$	90	28	3.7
$R_{0.4}F_1$	60	26.8	3.5

TABLE III

EXPERIMENTAL AND PREDICTED STRENGTH

Designation	Temperature °C	Experimental fcu N/mm^2	Predicted fcu N/mm^2	Experimental fct N/mm^2	Predicted fct N/mm^2
$R_{0.3}F_0$	60	24	23.62899	2	1.98573
$R_{0.35}F_0$	27	15.5	15.99689	1.7	1.638066
$R_{0.35}F_0$	90	26	26.02157	2.4	2.463123
$R_{0.4}F_0$	60	25	24.85255	2.3	2.31308
$R_{0.3}F_{0.5}$	27	15.7	15.55646	2.1	2.175524
$R_{0.3}F_{0.5}$	90	25	25.3671	3	2.951826
$R_{0.35}F_{0.5}$	60	26.2	26.2000	3.1	3.1000
$R_{0.4}F_{0.5}$	27	17.8	17.44354	2.3	2.349476
$R_{0.4}F_{0.5}$	90	27	26.4829	3.4	3.323174
$R_{0.3}F_1$	60	24.6	24.74745	3.3	3.28692
$R_{0.35}F_1$	27	18	18.00311	2.9	2.836934
$R_{0.35}F_1$	90	28	27.47843	3.7	3.761877
$R_{0.4}F_1$	60	26.8	27.17101	3.5	3.51427

A. Regression analysis

Experiments were performed using the Box–Behnken experimental design. Box–Behnken experimental design is a type of response surface methodology. Response surface methodology is an empirical optimization technique for evaluating the relationship between the experimental outputs and factors called x_1, x_2, and x_3. For obtaining the results for Box-Behnken design, analysis of variance has been calculated to analyze the accessibility of the model and was carried in Microsoft Office Excel 2007.

The significance of second-order polynomial for the tensile strength was assessed by carrying out analysis of variance. ANOVA is an analytical technique that is used to identify the importance of the model. The coefficient of determination (R^2) is defined as the ratio of the explained variation to the total variation, and is a measure of the degree of fit. A good model fit should yield an R^2 of at least 0.8. A *p*-value lower than 0.05 indicates that the model is statistically significant, whereas a higher value indicates that the model is not significant [1]. The R value obtained in the regression analysis for compression test is 0.9971 and split tensile test is 0.9967This means that the response model evaluated in this study can explain the reaction very well. The experimental and predicted values of compressive and split tensile strength are shown in the TABLE III.

. The model accuracy was checked by comparing the predicted and experimental strength. From the FIGURE II it is clear that majority of the model values falls on the line which indicates that predicted values and experimental values are the same.

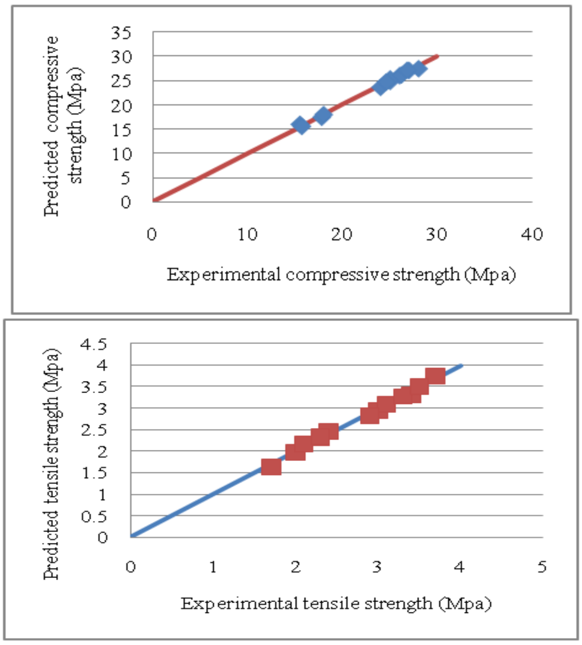

Figure II Comparison of Predicted and Experimental Strength

V. CONCLUSIONS

The conclusions obtained are

- As the concentration of sodium hydroxide increased compressive strength of geopolymer increased.
- Higher the ratio of sodium silicate-to-sodium hydroxide liquid ratio by mass, showed higher compressive strength of geopolymer concrete.
- The compressive strength of geopolymer concrete is gradually increased with prolonged curing period and significantly improved at curing period of 28 days.
- Increase in curing temperature in the range of 30°C to 90 °C increased the compressive strength of geopolymer concrete and longer curing time also increased the compressive strength.
- Geopolymer concrete up to120 minutes will not show any sign of setting and without any degradation in the compressive strength, resulted very little drying shrinkage and low creep.
- Water to geopolymer solids ratio has negative effect on the strength of geopolymer concrete.
- Another important observation was that curing under normal sunlight yielded strength of 16 N/mm^2..
- Split tensile strength of geopolymer concrete increased as percentage of steel fiber increased.
- Box Behnken design was successfully adopted. The model fitted the experimental data since R^2 approximates to 1 and also large F value.

ACKNOWLEDGMENT

I wish to express my deep sense of gratitude to all faculties of Department of Civil Engineering, M A College of Engineering, Kothamangalam. I thank God, the almighty for his blessings without which nothing would have been possible.

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