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Influence of Various Design Parameters on Compressive Strength of Geopolymer Concrete: A Parametric Study by Taguchi Method

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A B S T R A C T

Global warming is one of the severe environmental effects, which are faced by the current generation. Studies show that Carbon dioxide (CO_2) is the major cause of global warming and is mainly due to the huge production of Ordinary Portland Cement (OPC). Supplementary cementitious materials can reduce this effect by reducing the required materials instead of OPC for construction purposes. Geopolymer Concrete (GPC) is a new generation concrete, which does not require OPC. In this study, Fly Ash (FA) was used to produce GPC. Various parameters were considered and the design of the experiment was made using Taguchi's method and developed an empirical relation to predicting the compressive strength of GPC based on the different parameters. Thirty-six mixes were cast to determine the effect of curing temperature, curing time, rest period, the ratio of Alkaline Activator solutions (AAs), ratio of activators to FA, the molarity of NaOH and replacement level of FA with OPC on the compressive strength. The contribution of each parameter was estimated by ANOVA. Results show that the addition of OPC had a significant effect on the compressive strength of GPC. The mix with 20% OPC, 14M NaOH, curing temperature of 60ºC, curing time of 36h, a rest period of 48h, AAs to FA ratio 0.3 and ratio of alkaline solutions 2.5 was found to have the maximum compressive strength. A regression equation is developed to determine the compressive strength of GPC concerning the parameters considered.

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1. INTRODUCTION

Global warming is one of the major environmental problems, which affects all living creatures. The liberation of greenhouse gases such as CO_2 has a major role in global warming [1]. The permitted level of CO_2 in the atmosphere is 0.04% [2]. When the level of CO_2 increases beyond the permissible limit, global warming happens. OPC is one of the major binding materials that liberates CO_2 around 5-7% [3]. There are several research works undertaken to develop sustainable concrete by replacing OPC with other supplementary cementitious materials like industrial by-products. The production of cement releases greenhouse gas. The heating of limestone releases CO_2 directly, while the burning of fossil fuels to heat the kiln indirectly results in CO_2 emissions. The environmental issues associated with greenhouse gases, in addition to the depletion of natural resources, play a leading role in the sustainable development of the cement and concrete industry during this century. Due to scarcity of natural resources or growing concern over greenhouse gases or both, a time will come when the production of cement will have to be curtailed or cannot be increased to maintain the ecological balance [4]. Therefore, it is necessary to look for sustainable materials for the production of concrete. About 13-22% of CO_2 emission from OPC production can be reduced by using sustainable binding materials blended with OPC [3]. The Indian coal is of low grade having a high ash content of the order of 30 - 45% producing a large quantity of FA at coal/lignite based thermal power stations. The management of FA has been troublesome because of its disposal due to its potential of causing pollution of air and water. In the past decade,

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there has been a tremendous increase in the generation of FA; coal-based thermal power plants meet more than 70% of country's demand for electricity. At present, India produces approximately 180 million-tons of FA every year. Some of the problems associated with FA are large area of land required for disposal and toxicity associated with heavy metals leached to groundwater. FA was treated as a waste material and a source of air and water pollution until the last decade. However, at present it is considered as a resource material to produce different useful binding products. By increasing the utilization of FA, the emission of CO_2 can be reduced.

In the year 1987, Davidovits developed a new generation binding material, which is produced through the polymerization process of alumina-silicate source materials like FA, bottom ash, GGBS, etc., with the aid of AAs, and it is termed as GPC [2]. The production of GPC will reduce the emission of CO_2 by 80%. Two major environmental pollutions CO_2 emission and open landfill of FA are reduced by the production of FA-based GPC. The main constituents of GPC are silicon and aluminum that are provided by thermally activated natural materials (e.g. kaolinite or rice husk ash) or industrial by-products (e.g. FA or slag) and an alkaline activating solution, which polymerizes these materials into molecular chains and networks to create a hardened binder. It is termed alkali-activated concrete or inorganic polymer concrete [5-7]. Ambient cured GPC was made by using different alumino-silicate source materials such as slag, fly ash, etc. at CBRI, Roorkee. Also, they introduced lightweight GP sheets, solid bricks, hollow blocks, foamed bricks and solid blocks made of GPC. The production of GPC at ambient conditions by using different aluminosilicate source materials such as slag, FA, etc. resulted in the production of readymade lightweight GP sheets, solid bricks, hollow blocks, foamed bricks and solid blocks [8]. Dr. Genichi Taguchi observed that the ratio of time and money spending for engineering experiments and testing is higher than the efforts taken for making products. He felt that the process of inspection, screening and salvaging could not improve poor quality. This moved Taguchi to develop a new optimization method of the processes of engineering experimentation. He said that "Cost is more important than quality but the quality is the best way to reduce cost". He developed a statistical technique known as the Taguchi method [9]. Taguchi method is now used for different disciplines such as optimization of concrete mix, finding the optimum values for the ingredients in a mixture, etc [10,11]. Only a limited number of works are done by the Taguchi method to optimize the parameters according to different properties of Geopolymer concrete [11-13]. ANOVA was used to find the percentage of effect of each parameter. Partial replacement of FA was found to give good mechanical properties when compared with other proportions [14]. By the addition of cement in GPC, hardened properties increase whereas fresh properties decrease. Also, the concrete becomes more dense and compact. The optimum replacement level for OPC was found to be 10% [15, 16]. OPC provides excellent early and final compressive strength in the GPC mix in the absence of heat curing, but beyond 10% OPC addition reduced strength from 82.5% to 24.4% [17-19]. The combination of $NaOH+Na_2SiO_3$ was found to have high compressive strength and is suitable for structural applications. GPC mix having AAs to FA ratio of 0.35 to 0.45 and 12M & 16M NaOH solution, the ratio of AAs as 2.5 at a curing temperature of 90°C for 12h provided more than 60MPa strength with the curing period of 24 h at 60°C. Beyond 16h of curing time and more than 120°C temperature of curing time had no significant improvement on the strength of GPC [20]. A rest time of 30 minutes for the activator solution and increases in curing time provides good mechanical properties than the resting time of 24 h. Porosity and water absorption were found to decrease [15]. 14M NaOH solution provides a strength of 25-30 MPa. 90% of the compressive strength was achieved at a temperature of 70°C to 90°C and at a curing time of 18 to 24 h. According to [21] strength of the concrete reduces beyond 150°C due to overheating. The optimum value for activators to FA ratio was found 0.40 and beyond 16M NaOH solution does not provide strength to the concrete due to the improper polymerization [22].

The mechanical properties of FA-based GPC were investigated by the Taguchi method. Considered parameters include calcium aluminate cement (CAC) replacement (5, 10 and 20%), the concentration of NaOH (10, 12 and 14M) and activator to binder ratio (35, 40 and 45%). It was found that mix with 10M NaOH solution, 5% CAC replacement and 45% of activator to binder ratio exhibited good workability. In addition, 14M NaOH solution, 10% CAC replacement and 35% of activator to binder ratio exhibited maximum compressive strength of 56.8 MPa at 28 days of ambient curing. It was concluded that the CAC replacement ratio had a significant influence on the strength, whereas the workability of the concrete mix was influenced by the activator to binder ratio [23]. The mechanical properties of GPC with GGBS were examined at ambient curing conditions by Taguchi method and the considered parameters include binder content (400, 450 and 500 kg/m^3), AA to Binder content (Al/Bi) ratio (0.35, 0.45 and 0.55), sodium silicate to sodium hydroxide ratio (1.5, 2.0 and 2.5) and concentration of NaOH solution (10, 12 and 14M). Maximum compressive strength (60.4 MPa) was obtained after 7 days at ambient curing condition and the optimum value for each of the considered parameters are binder content of 450 kg/m^3, Al/Bi ratio of 0.35, sodium silicate to sodium hydroxide ratio of 2.5 and 14M NaOH solution. The addition of GGBS in the FA-based GPC has the advantage that heat curing can be avoided [12]. An investigation was carried out on the compressive strength of GPC by using the Taguchi method. It was found that

30% of GGBS, 50% of M-sand and activators to binder ratio of 0.40 showed maximum compressive strength [11]. Compressive strength and water absorption properties of FA-based GPC were investigated by Taguchi method carried out considering various parameters like OPC as FA replacement, NaOH concentration and curing temperature. It was found that maximum compressive strength of 64.39 MPa at 7 days of curing was obtained for the mix with 20% OPC, 15M NaOH solution and 70°C for 24 h. Similarly, minimum water absorption was obtained for the mix with 20% OPC, 10M NaOH solution and 80°C for 24h. Mechanical and durability properties of GPC were found to depend on the concentration of NaOH, amount of AAs, AAs to FA ratio, curing period and curing temperature [13]. In earlier studies, researchers have replaced FA with a maximum cement content of 15%. In this study, 20% FA was replaced. Parameters are not considered together in the earlier research works. In this research, seven parameters are considered together. Normally when considering more number of parameters together more experiments are needed for testing. But to reduce the number of experiments, Taguchi's method can be used. In the Taguchi method, the minimum number of experiments can be found which will provide the effects of all the parameters accurately at a low cost. This method was adopted for various engineering analysis to optimize various influencing parameters [6]. Taguchi experimental design reduces the cost, improves the quality and provides robust design solutions. The advantages of the Taguchi method over the other methods are that numerous factors can be simultaneously optimized and more quantitative information can be extracted from fewer experimental trials. From the critical analysis of the literature, it is evident that different parameters will influence the compressive strength of FA-based GPC. An attempt has been made to carry out a parametric study on the factors influencing the compressive strength of GPC.

2. DETAILS OF THE EXPERIMENT

2. 1. Materials

2. 1. 1. Fly Ash FA used in this research was obtained from the Mettur Thermal power plant, which is located in Salem, India. The obtained FA was found to contain 59.93% SiO_2, 19.66% Al_20_3, 2.82% Fe_2O_3, 3.33% CaO, 1.12% MgO, 0.22% K_2O, and 0.34% Na_2O through X-ray Diffraction (XRD) analysis. Following its chemical composition obtained, FA contains low Calcium content. Therefore, the obtained FA is termed as low calcium FA or Class-F FA. The specific gravity of Mettur FA was determined as 2.31 and the specific surface area of FA particle was found to be 320m^2/kg.

2. 1. 2. Ordinary Portland Cement (OPC) OPC 53 grade obtained from a local source was used for this research as an external calcium source for the setting GPC. The chemical properties of FA and OPC are given in Table 1.

2. 1. 3. Aggregates Manufactured Sand (M-Sand) was obtained from local supplies. Density, water absorption and specific gravity of M-Sand were found to be 1670 kg/m^3, 1.35% and 2.7, respectively. Coarse Aggregate (CA) was also obtained from the local source. Crushed stone aggregates of nominal diameter between 10mm and 20mm with density, water absorption and Specific gravity of CA were found to be 1760 kg/m^3, 0.5% and 2.9, respectively.

2. 1. 4. Alkaline Activator Solution Activator solution was made by combining the commercially available Sodium hydroxide (NaOH) pellets and Sodium Silicate (Na_2SiO_3) solution. NaOH solution was prepared by mixing the required quantity of 97-98% pure NaOH pellets with distilled water to get the desired molarity and kept for 24h to expel the heat produced during the mixing process. Na_2SiO_3 solution obtained from the local source was used in this research. Na_2SiO_3 has a pH value of 10-13, a specific gravity of 1.45-1.55g/cm^3 and a density of 1450-1550 kg/m^3. The total solid content present in the available sodium silicate solution is 45-55% by mass.

2. 2. Test Parameters The number of parameters considered and the levels for those factors were selected based on the literature review. In this research, seven different parameters were considered which can influence the compressive strength of GPC. The parameters considered are curing temperature, curing time, rest period, a ratio of AA solutions, a ratio of activators to FA, the molarity of NaOH and replacement level of FA with OPC. The details of considered parameters and the levels of each parameter are given in Table 2.

TABLE 1. The chemical composition of OPC and FA

Constituent	OPC (%)	FA (%)
Silica Oxide(SiO_2)	21.28	59.93
Aluminum Oxide(Al_2O_3)	4.33	19.66
Iron Oxide(Fe_2O_3)	1.85	2.82
Calcium Oxide(CaO)	64.30	3.33
Magnesium Oxide(MgO)	1.81	1.12
Sodium Oxide(Na_2O)	0.17	0.34
Potassium Oxide(K_2O)	0.71	0.22
Loss of ignition(LOI)	1.50	1.56

TABLE 2. Parameters and levels for compressive strength

Parameters	Level 1	Level 2	Level 3
OPC content (%)	0	10	20
Molarity of NaOH (M)	10	12	14
Curing temperature (°C)	60	80	100
Curing time (h)	12	24	36
Rest period (h)	24	48	-
AAs to FA ratio	0.30	0.35	0.40
The ratio of alkaline solutions	2	2.5	3

2. 3. Design of Experiment Taguchi method was used to develop the Design of Experiments (DOE) and to determine the minimum number of experiments to be carried out to completely understand the influence of these seven parameters [13, 24-27]. A robust design of the L_{36} orthogonal array was developed for compressive strength experimentation. Table 3 shows the different parametric combinations obtained by the Taguchi method to carry out the experiments. Thirty-six sets of experiments with different levels of factors were designed as per the Taguchi method and the developed L_{36} matrix is given in Table 3.

TABLE 3. L_{36} Matrix designed as per Taguchi method

Trial mixture	Rest Period (h)	Curing Temperature (°C)	Curing Time (h)	Ratio of Alkaline Solution	Molarity of NaOH (M)	Ratio of Activators to FA	Percentage of Cement (%)
T_1	24	60	12	2	10	0.3	0
T_2	24	80	24	2.5	12	0.35	10
T_3	24	100	36	3	14	0.4	20
T_4	24	60	12	2	10	0.35	10
T_5	24	80	24	2.5	12	0.4	20
T_6	24	100	36	3	14	0.3	0
T_7	24	60	12	2.5	14	0.3	10
T_8	24	80	24	3	10	0.35	20
T_9	24	100	36	2	12	0.4	0
T_{10}	24	60	12	3	12	0.3	20
T_{11}	24	80	24	2	14	0.35	0
T_{12}	24	100	36	2.5	10	0.4	10
T_{13}	24	60	24	3	10	0.4	10
T_{14}	24	80	36	2	12	0.3	20
T_{15}	24	100	12	2.5	14	0.35	0
T_{16}	24	60	24	3	12	0.3	0
T_{17}	24	80	36	2	14	0.35	10
T_{18}	24	100	12	2.5	10	0.4	20
T_{19}	48	60	24	2	14	0.4	20
T_{20}	48	80	36	2.5	10	0.3	0
T_{21}	48	100	12	3	12	0.35	10
T_{22}	48	60	24	2.5	14	0.4	0
T_{23}	48	80	36	3	10	0.3	10
T_{24}	48	100	12	2	12	0.35	20
T_{25}	48	60	36	2.5	10	0.35	20
T_{26}	48	80	12	3	12	0.4	0
T_{27}	48	100	24	2	14	0.3	10
T_{28}	48	60	36	2.5	12	0.35	0
T_{29}	48	80	12	3	14	0.4	10
T_{30}	48	100	24	2	10	0.3	20
T_{31}	48	60	36	3	14	0.35	20
T_{32}	48	80	12	2	10	0.4	0
T_{33}	48	100	24	2.5	12	0.3	10
T_{34}	48	60	36	2	12	0.4	10
T_{35}	48	80	12	2.5	14	0.3	20
T_{36}	48	100	24	3	10	0.35	0

2. 4. Preparation of Test Specimens For the desired concentration of NaOH solution for each trial mix, NaOH pellets were dissolved in distilled water. Prepared NaOH solution was added with Na_2SiO_3 solution and mixed thoroughly. Thirty minutes after the preparation of AAs solution, dry materials such as aggregates and binders were mixed in a mechanical mixer for about 2 minutes. After dry mixing of materials, AA solution was poured slowly into the dry mix along with the required water and mixed continuously. The materials were mixed for about 2 minutes until the concrete appears to be homogeneous. After the mixing, the GPC mixture was poured into the compressive strength cube mold of size 150mm × 150mm. The preparation of specimens and the slump details are shown in Figures 1 and 2, respectively. The specimens were cast and kept at room temperature for the corresponding rest period given in Table 3. After the completion of the rest period, the specimens were de-molded and kept in an electric furnace as per the specification given in Table 3. The inner dimensions of the furnace are 500mm × 500mm × 500mm. The sides and top of the furnace were lined with electrical heating coils embedded in refractory bricks. The specimens were heated uniformly on three sides [28]. Heat curing of specimens is shown in Figure 1A. Once the curing of specimens is completed, the specimens were allowed to cool naturally and the specimens were kept at ambient temperature until testing.

2. 5. Testing Method For determining the compressive strength, cubical GPC specimens were tested in a Compressive strength Testing Machine (CTM) of capacity 2000kN at the age of 28 days specimens is shown in Figure 1B. The load was applied to the specimen gradually and continuously at a rate of 14/N/mm^2/minute [29]. Three specimens were tested for each trial mix and the results were given as their average.

3. RESULT AND DISCUSSION

3. 1. Analysis of the Results During the present investigation, 108 cube specimens were tested. Workability for OPC blended GPC mix was tested following IS- 10262-2019 and slump of the mixes were maintained in the range of 100mm to 150mm [30]. The hardened properties of the OPC blended GPC specimens were tested following IS-516 [29]. From table 3, it can be seen that almost all the mixtures have 28 days compressive strength values above 30 MPa. The specimens correspond to 20% OPC as FA replacement, 10M concentration of NaOH solution, curing temperature of 60ºC for 36 h, rest period of 48 h, AA ratio of 2.5 and activator solution to FA ratio of 0.35. Minimum compressive strength was observed for the T_{15} specimen with an average strength value of 22.89 MPa. These specimens correspond to 14M concentration of NaOH solution, curing temperature of 100ºC for 12 h, rest period of 24h, alkaline solution ratio of 2.5 and activator solution to FA ratio of 0.35, cement content was zero for this mix. From the experimental results, it can be seen that the compressive strength of GPC increases with the increasing percentage of OPC.

According to Table 3, specimens having a rest period of 48h give better strength than the specimens having 24h rest period. This shows that the polymerization process continuous up to 48h. It is found that the specimens cured at 60ºC and 80ºC for 36h had higher than those of the specimens cured under other conditions. But specimens cured at 100ºC for 12h also show good compressive strength. This is following the findings of [20, 29]. They reported that the higher strength was observed at 90ºC for a curing period of 12 to 18h. From Figure 2, it can be seen that maximum strength was obtained for the specimens having 20% OPC replacement. It is reported that a 20% OPC replacement level was optimum [5]. Increasing the OPC level beyond this resulted in a decrease in the strength of the GPC due to extra calcium in the mix [30]. From Figure 2, it can also be seen that the variation in the concentration of NaOH between 10M and 14M was found to have a small effect on the compressive strength of GPC and 12M solution resulted in higher strength than the other molar solutions. This is following the findings of [20]. They observed that 12M NaOH solutions yielded maximum strength. Maximum strength was found when the ratio of AAs was 2.5 and the ratio of activators to FA was 0.35. This is following the finding of [20]. They reported that maximum strength was observed when the ratio of AAs was 2.5 and the activator to FA ratio was 0.35.

(a) (b)

Figure 1. (a) Heat curing of test specimens (b) Compression test on GPC cube

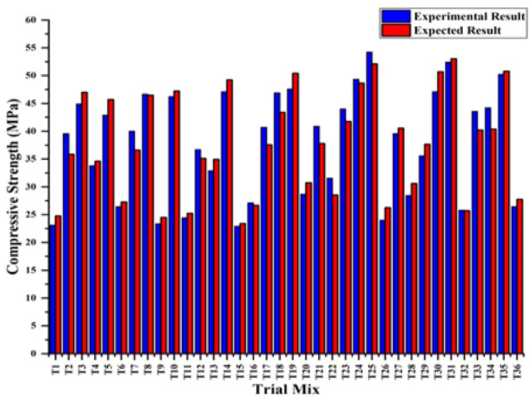

Figure 2. Comparison of the estimated and experimental compressive strength of GPC

Figures 3 (A, C, D, E and G) indicate the increase in the rest period, curing time, AA ratio, the concentration of NaOH, and addition of Additives (OPC) increase the compressive strength of GPC, whereas Figures 4B and 4F show that increase in curing temperature and AA-FA ratio declines the compressive strength of GPC decreases [15].

3. 2. Mathematical Model Based on the results, compressive strength for each parameter were described in Table 4. The main objective of this analysis is to find out the impact of considered key parameters and their contribution, i.e. OPC addition, molarity of NaOH, curing temperature, curing time, rest period, AA-FA ratio and ratio of activators solution on the compressive strength of GPC. From the ANOVA results for compressive strength of GPC, it is observed that addition of OPC as FA replacement is the most significant parameter with the highest contribution of 77.44%, whereas other parameters such as rest period, curing temperature, curing time, a ratio of alkaline solutions, the molarity of NaOH and ratio of activators to FA have the contributions of 2.12%, 0.21%, 2.38%, 1.82%, 1.37% and 0.96%, respectively. The compressive strength of GPC can be increased by the addition of OPC. Calcium oxide is a major compound in OPC which provides strength to the concrete. Calcium tends to react with the alkalis which result in additional hydration products and heat [31]. The produced heat also helps to improve the compressive strength of GPC by enhancing the curing temperature of the system. Beyond the 20% replacement level, the compressive strength of GPC decreases due to the utilization of available water for the hydration of OPC. The maximum increase in the compressive strength of OPC blended GPC was found to be 57.78% more than that of the GPC containing 0% OPC. An expression for the compressive strength of GPC was developed using a regression equation based on the obtained experimental results. The compressive strength (denoted by S), rest period (denoted by R), curing temperature (denoted by T), curing time (denoted by C), a ratio of alkaline solutions (denoted by A), the molarity of NaOH (denoted by M), a ratio of activators to FA (denoted by F) and addition of OPC as FA replacement (denoted by P) and the expression is given below.

$$S = 15.7 + 0.1319R - 0.0268T + 0.1630C - 0.41A + 0.761M - 25.0F + 1.133P \quad (1)$$

The result of the mathematical model was compared with the experimental results and the details are shown in Figure 2. From the figure, it can be seen that the developed mathematical model can predict the compressive strength of GPC accurately. The percentage errors in predicting the compression strength of GPC concerning the various parameters are shown in Figure 3. From Equation (1) it can be seen that the regression model can be used to predict the strength of GPC accurately. The percentage error is found to be less than 10.

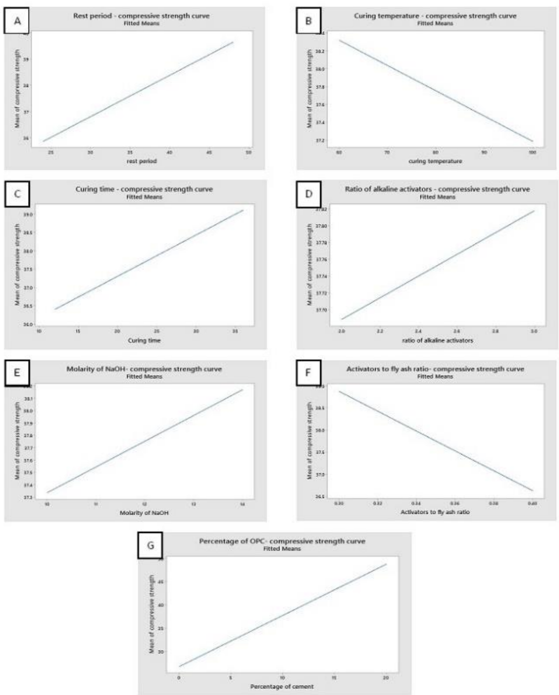

Figure 3. software stimulation of compressive strength of GPC Vs. Rest period, curing temperature, curing time, AA ratio, the concentration of NaOH, activator-FA ratio, the addition of additives

TABLE 4. ANOVA for compressive strength

Source	Sum of squares	Degree of freedom	Mean square	F-value	Contribution (%)
Rest Period(h)	90.22	1	90.22	3.39	2.12
Curing temperature(°C)	8.77	2	4.39	0.16	0.21
Curing time(h)	101.62	2	50.81	1.91	2.38
Ratio of Alkaline solutions	77.48	2	38.74	1.46	1.82
Molarity of NaOH(M)	58.41	2	29.20	1.10	1.37
Ratio of Activators to FA	41.03	2	20.51	0.77	0.96
OPC (%)	3302.92	2	1651.46	62.11	77.44
Error	584.96	22	26.59		13.71
Total	4265.41	35			100.00

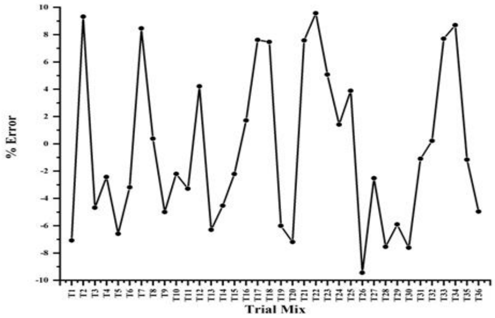

Figure 4. Percentage error for the estimated and experimental compressive strength of GPC

3. 3. Signal–to–noise Ratio (SN Ratio)

Optimum combination for the levels of the considered factors determined by using signal to noise ratio was calculated by using the following equations*:*

$$\frac{S}{N} = -10log\left(\frac{\bar{y}^2}{s^2}\right) \quad (2)$$

$$\frac{S}{N} = -10log\frac{1}{n}\sum y^2 \quad (3)$$

$$\frac{S}{N} = -10log\frac{1}{n}\sum\frac{1}{y^2} \quad (4)$$

The highest ratio of signal to noise ratio was considered as better for the optimum parametric combination [16]. SN ratio was calculated using Equation (4) and the best optimum combination were shown in Figure 5. It was observed that compressive strength of the mixture increases with the addition of OPC until 20% replacement, increases with a rest period of 48 h and molarity of NaOH of 14M. Maximum strength was achieved with the ratio of alkaline solutions of 2, activators to FA ratio of 0.3 and curing temperature of 60^{o}C for 36h.

When a higher concentration of NaOH solution is added with FA, it liberates a higher amount of silica and alumina. These two compounds influence the strength of the whole system. Also by the addition of OPC, induces the additional hydration products accompanied with a geo-polymeric binder to form the concrete [31]. From the SN ratio graph, the optimum parametric combination for higher strength of GPC was observed to be 20% OPC, 14M NaOH, curing temperature 60^{o}C, curing time 36h, rest period 48h, AA to FA ratio 0.3 and ratio of alkaline solutions 2.

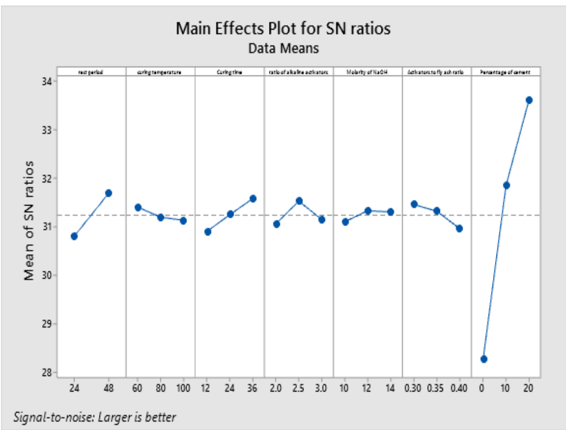

Figure 5. S-N ratio graph for compressive strength

4. CONCLUSIONS

Seven parameters that were expected to influence the compressive strength of GPC were considered for the parametric study. Taguchi method was used to design the experiment and a mathematical model was developed by using experimental results. The replacement of FA with OPC significantly improves the compressive strength of GPC. The optimum replacement level FA with OPC for GPC is 20%. The strength of the GPC mix was found to increase by 57.78% when OPC content was increased from 0 to 20%. From ANOVA, the addition of OPC was found to be the most significant factor for activating the required strength. From the research, the strength contributions of considered parameters are OPC (77.44%), curing time (2.38%), rest period (2.12%), the ratio of alkaline solutions (1.82%), molarity of NaOH (1.37%), a ratio of activators to FA (0.96%) and curing temperature (0.21%). The regression equations arrived with a high degree of accuracy can be utilized for the determination of the compressive strength of GPC with the considered parameters. The mix with 20% OPC, 14M NaOH, curing temperature 60^{o}C, curing time 36h, rest period 48h, AAs to FA ratio 0.3 and ratio of alkaline solutions 2 was found to have the maximum compressive strength.

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Persian Abstract

چکیده

گرمایش جهانی یکی از اثرات شدید زیست محیطی است که نسل کنونی با آن روبرو شده است. مطالعات نشان می دهد که دی اکسید کربن (CO_2)عامل اصلی گرم شدن کره زمین است و عمدتا به دلیل تولید عظیم سیمان پرتلند معمولی (OPC)است. مواد سیمانی تکمیلی می تواند با کاهش مواد مورد نیاز به جای OPC برای اهداف ساختمانی ، این اثر را کاهش دهد. بتن Geopolymer (GPC) یک بتن نسل جدید است که نیازی به OPC ندارد. در این مطالعه از Fly Ash (FA) برای تولید GPC استفاده شد. پارامترهای مختلفی در نظر گرفته شد و طراحی آزمایش با استفاده از روش تاگوچی انجام شد و یک رابطه تجربی با پیش بینی مقاومت فشاری GPC بر اساس پارامترهای مختلف ایجاد کرد. سی و شش مخلوط برای تعیین تأثیر دمای عمل آوری ، زمان پخت ، دوره استراحت ، نسبت محلول های فعال کننده قلیایی (AA)، نسبت فعال کننده ها به FA ، مولار NaOH و سطح جایگزینی FA با OPC بر روی فشار مورد استفاده قرار گرفت. استحکام - قدرت. سهم هر پارامتر توسط ANOVA برآورد شد. نتایج نشان می دهد که افزودن OPC تأثیر قابل توجهی بر مقاومت فشاری GPC داشت. مخلوط با ۲۰٪ OPC، ۱۴M NaOH ، دمای عمل آوری 60°C ، زمان پخت ۳۶ ساعت ، یک دوره استراحت ۴۸ ساعت ، نسبت AA به FA 0.3 و نسبت محلولهای قلیایی ۲.۵ دارای حداکثر مقاومت فشاری بود. یک معادله رگرسیونی برای تعیین مقاومت فشاری GPC در مورد پارامترهای مد نظر ایجاد شده است.