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Parametric Effects on Slump and Compressive Strength Properties of Geopolymer Concrete using Taguchi Method

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ABSTRACT

This paper represents the parametric effects on slump and compressive strength of aluminosilicate based Geopolymer concrete using by Taguchi method. A total of nine mix proportions were considered to evaluate the effect of sodium hydroxide (NaOH) solution, Solution/Binder (SB) ratio and the percentage of superplasticizer. Results indicated that the highest slump of 165 mm and 28 days compressive strength of 68.37 MPa was obtained for aluminosilicate based Geopolymer concrete with the superplasticizer, Solution to Binder (SB) ratio and extra water) parameters. By using the selected (Signal-to-Noise (SN) ratio graphs, the best combination of parameters for slump and compressive strength properties was also obtained. The mix with the best combination of parameters was considered and partially replaced with silica fume and rice husk ash. The inclusion of additional silica (in form of silica fume and rice husk ash as Ground Granulated Blast Furnace Slag (GGBFS) replacement), most significantly influenced the slump and compressive strength properties.

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1. INTRODUCTION

There is a rapid increase in the use of Ordinary Portland Cement (OPC) as primary binder in the preparation of concrete. The OPC manufacturing industry contributes to 7% (apporximately) of the total CO_2 emission as per International Energy Agency (IEA) [1,2,3]. On the other, the accumulation of industrial by-products in agricultural and residential lands poses varied threats and challenges to the country's productive development [4]. Hence, an extensive research has been initiated over the last few decades to explore alternate and suitable cementitious materials to mitigate this issue [3,5]. Thus considering a wide range of by-products in the manufacturing of concrete as a potiential replacement becomae a new scope of research.

In 1978, Joseph Davidovits invented the concept of "Geopolymer" [5, 6]. Since 1978, due to its excellent properties and environmental benefits, the popularity of Geopolymer Concrete (GC)has increased as a promising alternative to OPC concrete [7]. The production of GC has reduced the emission of CO_2 to 80% (approximately) as compared to OPC [6]. The major steps involved in the mechanism of polymerization include the dilution of Silica (Si) and Alumina (Al) in alkaline medium, the condensation of elements into monomers and the, formation of polymeric structure by polycondensation of monomers [8].

A vast number of research studies have been carried out on GC that is manufactured using low calcium content fly ash as primary binding material along with alkali solution (sodium hydroxide (NaOH)/sodium silicate (Na_2SiO_3) based) cured under oven temperatures [1,7,9]. Nevertheless, the manufacturing of GC under oven curing temperatures had minimized its usage to precast concrete elements [10]. Consequently, the field of applications using GC incorporating Ground Granulated Blast Furnace Slag (GGBFS) as partial substitute to fly ash at ambient curing came into existence[10-15]. Several studies focused on setting time, workability and

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hardened properties of GGBFS/fly ash-based mortar and concrete under ambient temperature [16-20]. It is outlined that the partial substitution of GGBFS improves the setting time and compressive strength. Neverthless a reduction in workability was also observed [16-20].

Taguchi method is a robust designing method which is used to optimize the number of experiments and to analyse the parametric effects on test results to identify the best leve1 of each factor. It is based upon the Signal to Noise (SN) ratio. The measure of robustness is used to identify the controllable factors which minimize the variability in a product or process by reducing the effects of noise factors (uncontrollable factors). The design factors and the process parameters that can be controlled are known as control factors. The factors which cannot be controlled during production, but can be controlled during experimentation are known as noise factors. In Taguchi design experiments, noise factors that cause variability in the results facilitate the identification of optimal control factor settings. It can be identified that the higher values of the SN ratio will reduce the effects of the noise factors. There are three types of SN ratio namely, i) Larger is the better, ii) Nominal is the better, and iii) Smaller is the better. Based on the requirement the specific SN ratio should be selected as indicated in the Table 1. In this study, Larger is the better, is selected to minimize the effects of noise factors. The best combination of parameters can be analysed by an individual response using Taguchi method. Only a limited number of research studies have considered for the Taguchi method to optimize the parameters according to different properties of Geopolymer concrete, to the knowledge of the authors [21-25].

Therefore, the main aim of this paper is to identify the best combination of mixing proportion in terms of slump and compressive strength properties of GC under ambient curing. Taguchi analysis method is used to identify the best combination of mixing parameters of GC. In this study, 70% GGBFS and 30% fly ash is selected as the primary binder (after a number of trial runs done in the research laboratory). The parameters selected for this study are Solution to Binder (SB) ratio, percentage of superplasticizer and extra water content, and the properties considered are the slump and compressive strength. After achieving the best combination of mix parameters, silica fume and rice husk ash are partially replaced to GGBFS. Further, slump and compressive strength tests were carried out to understand the role of silica fume and rice husk in Geopolymer concrete.

TABLE 1. Selection of SN ratio

Signal-to-noise ratio	Goal of the experiment	Signal-to-noise ratio formulas
Larger is better	Maximize the response	$S/N = -10 * \log(\Sigma(1/Y^2)/n)$
Nominal is better	Target the response and you want to base the signal-to-noise ratio on standard deviations only	$S/N = -10 * \log(\sigma^2)$
Smaller is better	Minimize the response	$S/N = -10 * \log(\Sigma(Y^2)/n))$

2. EXPERIMENTAL DETAILS

2. 1. Materials

GGBFS, silica fume and rice husk ash is supplied by Astra chem Pvt Ltd, India. Fly ash is obtained from North Chennai Thermal Power Station, India. The elemental composition of the by-product materials is represented in Table 2. Natural river sand (Zone - II, as per IS: 383-1970) is used as fine aggregate after sieving in 1.18 mm sieve. Normal coarse aggregate with a size of 12 mm is used. The specific gravities of coarse aggregate and fine aggregate are reported as 2.6 and 2.7 respectively. Sodium based silicate solution (Na_2O-15%, SiO_2-30%, H_2O-55%, with modular ratio of 2) is obtained from Kiran Global Chem Pvt, India. The sodium hydroxide flakes with 97% puritywas supplied by Sunshine Chemicals, India. The high range water reducer used in research work is commercially available Master Glenium SKY 8233 which is supplied by BASF Construction Chemicals.

2. 2. Design of Experiments

Taguchi method is used to design the experiments by considering three factors with three levels each using Minitab17 software. The three factors considered in this are SB ratio (0.5,

TABLE 2. Chemical composition of material binder

Components	GGBFS	Fly ash	Silica fume
CaO	33.4%	3.42%	0.001%
Al_2O_3	13.02%	29%	0.04%
Fe_2O_3	2.54%	11.01%	0.04%
SiO_2	31.03%	51.4%	99.86%
MgO	7.73%	0.25%	-
Loss on Ignition	0.26%	1.44	0.015%
Glass Content (%)	91%	-	-
Specific gravity	2.86	2.74	2.63

TABLE 3. Parameters and their proportions

Factors	Proportion 1	Proportion 2	Proportion 3
SB ratio	0.5	0.55	0.6
Superplasticizer (%)	2	4	6
Water	10	12	14

0.55, 0.6), percentage of superplasticizer (2, 4, 6%) and extra water (10, 12, 14%) are reported in Table 3. A total of nine mixes were generated using Taguchi $L_9 (3^3)$ array as reported in Table 4. The concentration of sodium hydroxide 12M is kept constant.

2. 3. Preparation of Samples The raw materials are mixed for 2 minutes using a pan mixer. Later, the solution content is added slowly and mixed for another 5 minutes. Immediately after mixing, the fresh concrete is tested for workability using slump cone test and then the concrete is cast in 100 mm size steel moulds with proper compaction and placed on a vibrator for 10 seconds. The specimens were subjected to ambient curing (25^0C ± 2^0C) for 24 hours. Following this, the specimens are removed from the moulds and kept for 7, 28, and 90 days for ambient curing.

3. RESULTS AND DISCUSSION

3. 1. Slump Value The slump value of Geopolymer concrete has been tested using a normal slump cone test as per IS 7320-1974. The dimensions of the slump cone are top diameter-10 cmm, height-30 cm and bottom diameter-20 cm. The concrete has been placed into the cone in three layers and tamped properly to remove the air voids. The cone is then lifted vertically and the readings are noted using a steel scale. The slump values of nine mixes are as shown in Figure 1. The minimum slump of 63 mm is achieved by the mix consisting of 0.5 SB ratio, superplasticizer 2% and extra water 10%. The maximum slump value of 150 mm is achieved in the mix consisting of 0.6 SB ratio, 6% superplasticizer and 12% extra water (Table 5). The slump value is significantly influenced by the three factors: SB ratio, Superplasticizer and water content. It clearly indicates that with an increase in the parameter levels, the workability also increases. However, to analyze the individual parameter that influences the slump value, Taguchi analysis was conducted using Minitab17 software.

From Figure 2, with the help of SN ratio's the individual effect of parameters has been determined. Firstly, SB ratio significantly influences the slump

TABLE 4. Taguchi mix proportions

Mix Id's	SB ratio	Superplasticizer (%)	Water (%)
TM1	0.5	2	10
TM2	0.5	4	12
TM3	0.5	6	14
TM4	0.55	2	12
TM5	0.55	4	14
TM6	0.55	6	10
TM7	0.6	2	14
TM8	0.6	4	10
TM9	0.6	6	12

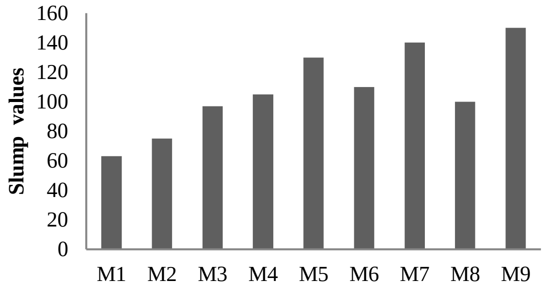

Figure 1. Slump values of Taguchi mixes

TABLE 5. Test results of Geopolymer concrete

Mix ID	Slump (mm)	Compressive strength (MPa)		
		7 days	28 days	90 days
M1	63	58	66.8	68.4
M2	75	53.1	62.2	64.2
M3	97	49.4	57.9	60
M4	105	53	60.12	62.6
M5	130	47.66	56.77	59.4
M6	110	54.8	63.4	66.74
M7	140	44.9	57.05	60.45
M8	100	54	61.45	64.87
M9	150	43.2	52.24	54.29

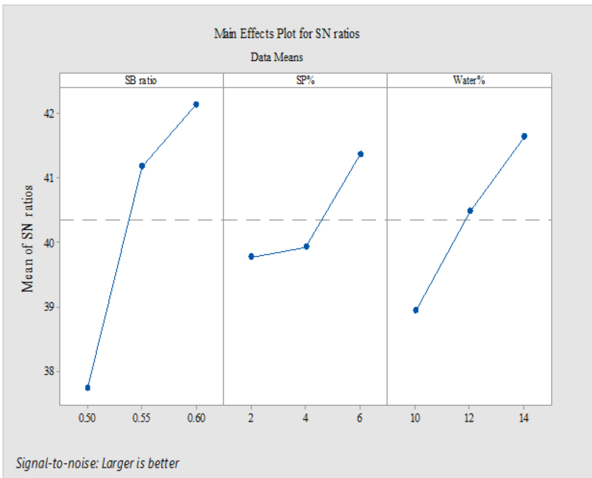

Figure 2. Main effects plot of SN ratios for slump

values. The slump value gradually increases with increase in parameter level of SB ratio from 0.5 to 0.6. The second parameter that influences the slump value is the extra water content. When extra water content is increased from 10 to 14%, there is a linear increment in the slump value. The third parameter, the percentage of superplasticizer also affects the workability properties. With a change in the parameter levels of superplasticizer from 2 to 4%, a slight increase in workabilityis achieved. When this is futher increased from 4 to 6%, a higher rate of workability is noticed.

3. 2. Compressive Strength A total of nine mixes (M1 to M9) have been cast and subjected to ambient curing. The compressive strength test was conducted as per to IS 516: 1959. The compressive strength of the nine mixes was tested at 7, 28, and 90-days age of concrete, and the average strength of the three specimens are reported in Table 5. The highest compressive strength of 68.4 is achieved with the mix of SB ratio-0.5, 2% superplasticizer and 10% extra water. The lowest compressive strength of 54.29 is achieved with mix that has SB ratio of 0.6, 6% superplasticizer and 12% extra water as shown in Figure 3. However, to deeply understand the effect of parameters on compressive strength, Taguchi analysis is conducted using Minitab17 software. From Figure 4, the first parameter to affect the strength properties is found to be the superplasticizer. It is observed that the strength properties gradually decrease with an increase in the superplasticizer. The second parameter that affects the strength properties is the SAS/Binder content. Even with a change from 0.5 to 0.55, there is a drastic reduction in the strength. Further increasing it from 0.55 to 0.6, indicates a slight reduction in the strength properties. However, there is not much effect of extra water (10, 12, 14%) on the strength properties.

The selection of the best mix proportion is considered in terms of both slump and compressive strength properties of GGBFS Geopolymer concrete. The mix

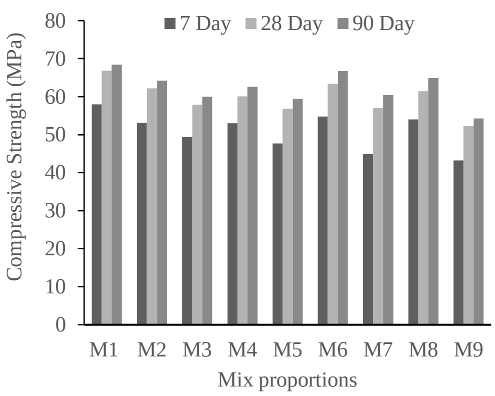

Figure 3. Compressive strength of Taguchi mixes

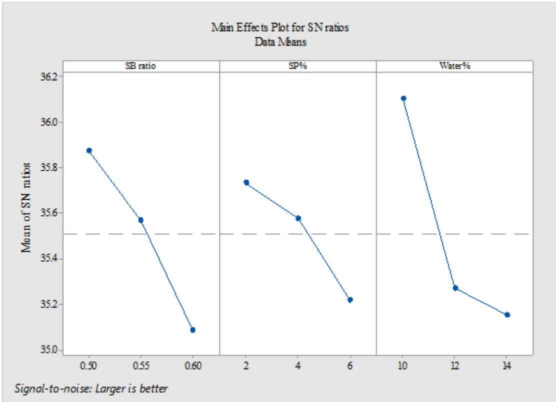

Figure 4. Main effects plot of SN ratios for compressive strength

with SB ratio of 0.5, 2% superplasticizer and 10% extra water has produced 63 mm slump and compressive strength of 66.8 MPa for 28 days The mix with SB ratio of 0.55, 6% superplasticizer and 10% extra water content has produced 110 mm slump and compressive strength of 63.4 MPa for 28 days. The mix with SB ratio of 0.6, 4% superplasticizer and 10% extra water content has produced 100 mm slump and compressive strength of 61.45 MPa for 28 days. From Taguchi analysis, the best parameter levels are considered as follows: SB ratio 0.5, Superplasticizer 4% and extra water 14%. MID10 is designated as the optimum mix from the Taguchi analysis as reported in Table 5. Finally, the mix MID10 is seen to have achieved 165 mm slump and 68.37 MPa compressive strength at 28-days.

3. 3. Effects of Silica Fume and Rice Husk Ash The mix MID10 is considered as the best parametric combination which is examined further with GGBFS is partially replaced by silica fume and rice husk ash such as 0, 5, 10, 15, and 20%, respectively. The test results are reported in Table 6.

TABLE 6. Effects of silica fume and rice husk ash

Mix ID	Slump (mm)	Average Compressive strength (MPa) @ 28 days
MID10	165	68.37
M10SF5	175	71.05
M10SF10	185	78.42
M10SF15	205	80.1
M10SF20	210	78.8
M10RA5	170	69.4
M10RA10	180	74.25
M10RA15	185	73.02
M10RA20	190	71.2

3. 3. 1. Effects on Slump The Geopolymer concrete slump values are significatly influenced by silica fume and rice husk ash as shown in Figures 5 and 6. The highest slump of 205 mm was achieved with the mix of 20% silica fume as compared to the mix of 0% silica fume. The slump growth rate increases about 27.2% with 20% silica fume as compared to control mix (Table 6). On the other hand, rice husk ash also significantly affects the slump value of Geopolymer concrete. The maximum replacement of 20% rice husk ash to GGBFS results in an increase in the slump value of about 15.5% as compared to the control mix (0% rice husk ash). This is due to the large surface area of the materials with fine particles that improves the workability of the Geopolymer concrete. However, it has been observed that the slump value is higly influenced by the mixes of silica fume as compared to the mixes of rice husk ash. This is due to the larger surface area in rice husk ash as compared to silica fume. Increase in dosage of fine particles leads to an increase in the demand of water content.

3. 3. 2. Effects on Compressive Strength The test results show that the silica fume and rice husk ash play a significant impact on compressive strength of GC as represented in Figures 7 and 8. The mix 15% silica fume has achieved the highest compressive strength of 80.1 MPa at 28-days as compared to other mixes in the experiment. The growth rate of compressive strength has increased about 17.1% with partial replacement of silica fume (15%) to GGBFS. The addition of silica content in the mix leads to an improvement in the strength of GC [26]. However, the partial replacement of silica fume beyond 15% results in a slight decrease in strength. This is due to the over dose of silica content in the mixtures which hinders the geopolymerization under ambient curing [27].

On other hand, the rice husk ash also has shown significant effect on compressive strength as shown in Figure 8. The growth rate increases about 8.6% with partial replacement of 10% rice husk ash to GGBFS in the mix. Also, the partial replacment of GGBFS with rice husk ash beyond 10% tends to decrease the compressive strength .The extra rice husk ash which is rich in silica

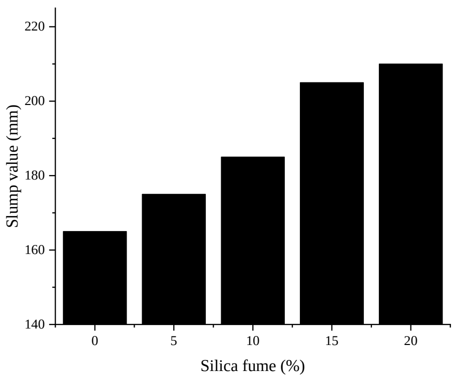

Figure 5. Effect of silica fume on slump

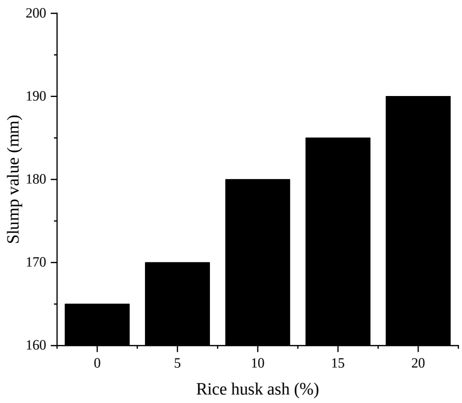

Figure 6. Effect of rice husk ash on slump

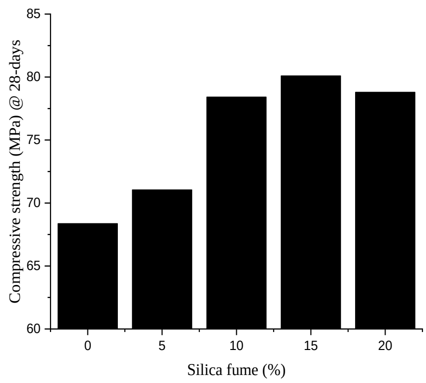

Figure 7. Effect of silica fume on Compressive strength

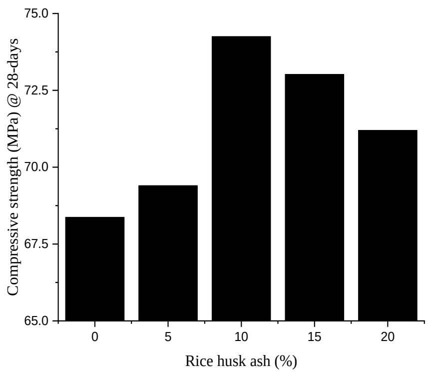

Figure 8. Effect of rice husk ash on Compressive strength

causes a problem in unreactive silica that leads to the rise in Si/Al ratio of Geopolymer concrete. This is mainly due to the effect of geopolymer concrete in the compressive strength of the mixes of rice husk ash beyond 10%. The mixes which are partially replaced with fly ash and micro silica, resulted in a decrease in the strength at ambient curing condition. The reason for decrease in strength was due to a decrease in the intensity of calcium [28], polymerization that was delayed and the hindered formation of Ca-Al-Si gel [29]. The combination of GGBFS with partial replacement of silica rich materials thus seens to be suitable under ambient curing.

4. CONCLUSION

The optimum mix M10 designed from the Taguchi analysis has achieved 165 mm slump and 68.37 MPa compressive strength at 28-days. The highest slump of 205 mm was achieved with the mix of 20% silica fume as compared to the mix of 0% silica fume. The slump growth rate increases about 27.2% with 20% silica fume as compared to control mix. The maximum replacement of 20% rice husk ash to GGBFS resulted in, an increase in the slump value of about 15.5% as compared to control mix. The growth rate of 17.1% increment in compressive strength has been observed with partial replacement of silica fume (15%) to GGBFS. Additionally, there is an 8.6% an increase in the growth rate with partial replacement of 10% rice husk ash to GGBFS in the mix. Beyond 10% replacement of the rice husk ash to GGBFS, there is decreasing trend in the growth rate under ambient curing.

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Persian Abstract

چکیده

این مقاله نشان دهنده اثرات پارامتری بر شیب و مقاومت فشاری بتن ژئوپلیمر بر پایه آلومینوسیلیکات با استفاده از روش تاگوچی است. در مجموع نه نسبت مخلوط برای ارزیابی اثر محلول هیدروکسید سدیم (NaOH) ، نسبت محلول / بایندر (SB) و درصد فوق روان کننده در نظر گرفته شد. نتایج نشان داد که بیشترین کسری 165 میلی متر و 28 روز مقاومت فشاری 68/28 مگاپاسکال برای پارامترهای فوق روان کننده ، نسبت محلول به اتصال دهنده (SB) و آب اضافی برای بتن ژئوپلیمر بر پایه آلومینوسیلیکات بدست آمد. با استفاده از نمودارهای انتخاب شده نسبت سیگنال به سر و صدا (SN) ، بهترین ترکیب پارامترها برای خواص مقاومت در برابر افت و فشار نیز بدست آمد. مخلوط با بهترین ترکیب پارامترها در نظر گرفته شد و تا حدی با بخار سیلیس و پوسته برنج جایگزین شد گنجاندن خاکستر اضافی سیلیس به صورت بخار سیلیس و خاکستر پوسته برنج به عنوان جایگزینی سرباره کوره بلند (GGBFS) ، به طور قابل توجهی بر خصوصیات افت و مقاومت در برابر فشار تأثیر می گذارد.