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Using the Taguchi method to optimize the compressive strength of geopolymer mortars

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ABSTRACT

This paper presents the use of the Taguchi method to optimize the compressive strength of geopolymer mortars. The geopolymer was produced from fly ash as a prime material and ordinary Portland cement (OPC) as additive. Fly ash was partially replaced with OPC in the geopolymer mixtures to enhance the compressive strength. The dosage of OPC, the concentration of sodium hydroxide solution (SH), and the curing temperature were considered as the influencing factors on the compressive strength of geopolymer mortars. Three levels of each factor were chosen to carry out this research. As a result, the orthogonal array L9 of the Taguchi method was used to design the experiments. The results of the experiments were analyzed by the signal to ratio (SNR) and the analysis of variance (ANOVA). This analysis has revealed that the least significant factor in terms of strength contribution is the dosage of OPC content, whereas the curing temperature is the most important factor in terms of strength contribution. This research shows that the optimized value of 7-day compressive strength was obtained in the mixture containing 20% of OPC that was prepared by SH of 12 M concentration and cured at 100oC. In addition, the geopolymer mortar produced by 30% of OPC and SH of 12 M concentration and cured at 100oC gained the maximum compressive strength at 28-day age.

1. Introduction

Fly ash-based geopolymer is a synthesized inorganic polymer attracting much research in recent years because of its strength and durability (Palomo et al., 1999; Chindaprasirt et al., 2007; Guo et al., 2010; Somna et al., 2011; Ryu et al., 2013; Atis et al., 2015). Fly ash provides a prime aluminosilicate source that reacts with alkaline activators to form the complex polyhydroxy-silicoaluminate (Shi et al., 2011). The geopolymer synthesis depends on the main aluminosilicate source and the alkali-activating condition. Hence, the final product of geopolymerization can be N-A-S-H gel in the low-calcium system, C-(N)-A-S-H gel in intermediate-calcium gel, and C-A-S-H gel in the high-calcium system (Luukkonen et al., 2018).

Fly ash-based geopolymer has produced the mortar specimens reached 120 MPa of the compressive strength and 15 MPa of the flexural tensile strength (Atis et al., 2015). Thus, it is eligible to replace ordinary Portland cement (OPC) in order to reduce the facing challenges of the cement industry, such as requiring a high cost for energy, reducing consumption of natural materials, and reducing carbon dioxide emissions. It is known that the cement manufacturing in the world has consumed a huge amount of energy and has released about 36.9 Gt carbon dioxide emissions to the atmosphere from 1928 to 2017 (Andrew, 2018). The worldwide production of cement achieved 4.1 billion metric tons in 2018. The Vietnam cement production reached approximately 80 million metric tons in 2018 that was reported by the U.S Geological Survey (Bernhardt and Reilly, 2019). Hence, replacing OPC by geopolymer in the construction field has become increasingly important.

Compressive strength of mortar or concrete is one of the most significant properties deciding its application on the structure. Previous studies have demonstrated that the influencing factors on the compressive strength of geopolymer mortars or geopolymer concrete were the used materials, the curing condition, and the concentration of alkaline activator solution. When fly ash was partially replaced with OPC in the geopolymer mixtures

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leading to improve the compressive strength of geopolymer concrete (Pangdaeng et al., 2014; Mehta and Siddique, 2017; Nuaklong et al., 2018; Nath and Sarker, 2015). For instance, the compressive strength of geopolymer mortar without OPC at 28 days achieved 18.3 MPa, while that of geopolymer mortars containing 5%, 10%, and 15% of OPC achieved 32.4 MPa, 45.0 MPa, and 55.0 MPa, respectively (Mehta and Siddique, 2017). An increase of 10% compressive strength was also observed in the recycled aggregate geopolymer concrete using 5% of OPC as fly ash substitution (Nuaklong et al., 2018). Moreover, the use of 5% OPC produced 50 MPa of the compressive strength for geopolymer mortar samples and 40 MPa of the compressive strength for geopolymer concrete samples at 28 days cured at room temperature (Nath and Sarker, 2015). This increase resulted from the formation of geopolymeric gel phases combined with calcium silicate hydrated (C-S-H) gel phase (Suwan and Fan, 2014). Furthermore, the compressive strength of geopolymers containing OPC as additive cured at ambient temperature was approximately the same as that of geopolymers without OPC cured at 40oC (Pangdaeng et al., 2014).

Meanwhile, it was found that the curing condition played an important role in geopolymerization process. Pangdaeng et al. (2014) supposed that the geopolymer samples cured at 40oC for 24 hours obtaining the higher early compressive strength than the others cured at ambient temperature. This phenomenon was also observed by Rovnaník (2010) when his specimens were cured at 60^{o}C or 80^{o}C for 24 hours. The compressive strength of his geopolymer mortars attained as equivalent as that of OPC mortar cured at ambient temperature for 28 days. Atis et al. (2015) manifested that the higher temperature the specimens were cured, the higher strength they gained. These results related to the geopolymerize degree that would be increased in elevated temperatures.

In addition, a number of published studies believed that there was an optimal concentration of alkaline activator solution that provided the maximum value of the compressive strength (Atis et al., 2015; Görhan and Kürklü, 2014). The increase in concentration caused more dissolving of fly ash, leading to a better geopolymerization (Alvarez-Ayuso et al., 2008). However, the concentration of the alkaline activator solution exceeded the optimal point resulted in the strength decrease owing to the coagulation of silica (Rattanasak and Chindaprasirt, 2009).

Reviews of literature show that many parameters affect the compressive strength of geopolymers. Thus, the optimization of influencing parameters is very important from the aspect of cost reduction. The design of experiments by the Taguchi method is now widely used to analyze and optimize the influencing parameters. Olivia and Nikraz (2012) have applied the Taguchi method to optimize the mixtures of fly ash geopolymer by considering four influencing factors, including aggregate content, an alkaline solution to fly ash ratio, sodium silicate to sodium hydroxide ratio, and curing method. The optimum levels of curing temperature, curing time, and sodium hydroxide concentration to provide the maximum compressive strength of ash-based geopolymer was found by nine series of experiments based on L9 Taguchi's array in an investigation of Riahi et al. (2012). Panagiotopoulou et al. (2015) investigated the effects of alkali content, alkali kind, and silicon content in the activation solution on the compressive strength of alkali-activating fly ash binders by utilizing the L_{16} orthogonal array with four levels of each influencing factor. Recent researches demonstrated that the Taguchi method is an effective approach to improve the product and process quality. Therefore, this study deals with optimizing the compressive strength of geopolymer mortars containing OPC as a part of the aluminosilicate source. Particularly, a curing regime and a concentration of alkali activator solutions were considered as these main influencing factors resulting in the optimal compressive strength. Taguchi L_9 orthogonal array has been used for conducting the experiments. Next, the analysis of the signal to ratio (SNR) and the analysis of variance (ANOVA) was applied on the obtained results to determine the best condition of each parameter.

2. Research method and experimental program

2.1. Research method

Taguchi method since the late 1940s is a highly effective method to optimize the process of engineering experimentation (Roy, 1990). This method constructs the especial tables known as "orthogonal arrays" that make the design of experiments easily and consistently. For example, the orthogonal array L_9 has been provided by the Taguchi method to conduct the experimental design for three levels of four factors (Table 1), whereas a full factorial design requires 3^4=81 runs. As can be seen in Table 1, the orthogonal array L_9 shows 9 trial conditions with various levels (i.e., level 1, level 2, and level 3) to study the quality of products and processes through a minimum number of experiments (Roy, 1990).

Table 1: The orthogonal array L_9 of the Taguchi method for three levels of four factors

Trial no.	Factor A	Factor B	Factor C	Factor D
1	Level 1	Level 1	Level 1	Level 1
2	Level 1	Level 2	Level 2	Level 2
3	Level 1	Level 3	Level 3	Level 3
4	Level 2	Level 1	Level 2	Level 3
5	Level 2	Level 2	Level 3	Level 1
6	Level 2	Level 3	Level 1	Level 2
7	Level 3	Level 1	Level 3	Level 2
8	Level 3	Level 2	Level 1	Level 3
9	Level 3	Level 3	Level 2	Level 1

In the Taguchi method, a signal to noise ratio (SNR) as shown in Eq. 1 has been introduced to analyze the quality characteristics. A high value of SNR implies that the signal is much higher than the random effects of the noise factors. Thus the optimal level of the factors is the level that has the greatest SNR.

$$SNR = -10Log_{10}(MSD) \tag{1}$$

The mean squared deviation (MSD) is described differently for each of the quality characteristics. For smaller is better,

$$MSD = \frac{1}{n}(y_1^2 + y_2^2 + \ldots) \tag{2}$$

For nominal is the best,

$$MSD = \frac{1}{n}[(y_1 - m)^2 + (y_2 - m)^2 + \ldots] \tag{3}$$

For bigger is better,

$$MSD = \left[\frac{1}{n}\left(\frac{1}{y_1^2} + \frac{1}{y_2^2} + \ldots\right)\right], \tag{4}$$

where y_1, y_2 =the results of the experiment; m=the target value of results; n =number repetitions (y_i).

In addition, the experimental results were applied the analysis of variance (ANOVA) to determine the percent contribution of each factor. The optimal process parameters can be predicted based on the results of ANOVA and SNR. Finally, the experiment would be made to verify the optimum condition obtained from the parameter design.

In regard to the compressive strength of geopolymer mortars, an aluminosilicate source, a concentration of alkaline activator solution, and a curing condition were considered main influencing parameters. Therefore, the dosage of OPC as fly ash replacement in the mixture, the concentration of sodium hydroxide solution (SH), and the curing temperature was chosen to optimize the compressive strength of geopolymer mortars in this present work. Based on the published research, three levels of each factor were selected to carry out the experiments (Table 2).

Table 2: Three levels of influencing factors in the design of the experiment by Taguchi method

Factor	Symbol	Level 1	Level 2	Level 3
The dosage of OPC (%)	A	10	20	30
The concentration of SH (M)	B	8	10	12
The curing temperature (°C)	C	25 (Ambient)	60	100

The orthogonal array L_9 of the Taguchi method was selected to design the experiments (Table 1). As a result, nine experiments, as listed in Table 3 were conducted to analyze the effects of the influencing parameters and optimize the compressive strength of geopolymer mortars.

Table 3: The conducted experiments based on the orthogonal array L_9 of the Taguchi method

Trial no.	The dosage of OPC (%) (Factor A)	The concentration of SH (M) (Factor B)	The curing temperature (°C) (Factor C)
1	10	8	25
2	10	10	60
3	10	12	100
4	20	8	60
5	20	10	100
6	20	12	25
7	30	8	100
8	30	10	25
9	30	12	60

2.2. Experimental program

2.2.1. Material used

Fly ash (FA) is a primary alumino-silicate source to produce the geopolymer in this research. In order to enhance the compressive strength of mortar samples prepared by geopolymer, ordinary Portland cement (OPC) was partially replaced with fly ash in the mixtures. The chemical composition of FA and OPC was determined by the X-ray fluorescence (XRF) apparatus, as shown in Table 4.

The alkaline activator of a geopolymer is a sodium hydroxide solution (SH). The SH was prepared by dissolving sodium hydroxide (NaOH) pellet of 99% purity with potable water with various concentrations before using at least 24 hours.

Natural silica sand conforming to the requirements for graded standard sand (Table 5) in Specification C778 (ASTM, 2009) was used for making test samples.

Table 4: The chemical composition of FA and OPC (wt.%)

Chemical compositions	FA	OPC
SiO_2	47.63	20.77
Al_2O_3	21.72	4.59
Fe_2O_3	11.45	3.34
CaO	11.16	63.22
K_2O	3.96	0.74
TiO_2	1.80	-
SO_3	0.68	2.37
SrO	0.54	-
P_2O_5	0.36	-
MnO	0.17	-
MgO	-	1.88
Others	0.53	3.09

Table 5: Standard sand

Characteristics	Graded Sand
Grading, percent passing sieve:	
1.18 mm (No. 16)	100
850 µm (No. 20)	100
600 µm (No. 30)	98
425 µm (No. 40)	70
300 µm (No. 50)	25
150 µm (No. 100)	4

2.2.2. Mixing proportion

Nine mixtures were prepared following the orthogonal array L_9 as listed in Table 3. The OPC was replaced fly ash at three ratios (i.e. 10%, 20%, and 30%). The concentration of SH was designed at 8 M, 10 M, and 12 M. And, the specimens were cured at three levels (25°C, 60°C, and 100°C). The ratio of alkali-activating solution to fly ash was kept constant at 0.4 by weight for all mixtures. Water was added to react with OPC in the hydration process called the hydrated water. The hydrated water and OPC ratio also were kept constant at 0.4 by weight for all mixtures. The proportions of mortar shall be one part of the binder (FA+OPC) to 2.75 parts of standard sand.

2.2.3. Sample preparation and testing approach

The cube specimens with a 50 mm dimension were produced by using the geopolymer mixtures presented in Table 6 to measure the compressive strength. In the beginning, mixing of FA and the alkaline solution was done for thirty seconds. At the same time, OPC was mixed with the hydrated water for thirty seconds. Then, two mixtures were combined to form a binder by mixing for one minute. In the final stage, the standard sand and the extra water were poured in the matrix and mixed for approximately four minutes until a homogeneous mixture was obtained. Immediately after mixing, the fresh mixture was cast in two layers into the molds, and each layer was compacted by a vibrating table for 10 seconds. Then, the specimens were cured at different temperatures.

The specimens of MO1, MO6, MO8 mixtures were covered with a plastic sheet to prevent moisture loss and stored in the room where the temperature in a range of 23°C to 27°C and the relative humidity of 70 ± 10%. The others were placed in the oven at 60°C or 100°C (Table 6) for 24 hours. After 24 hours of curing, all specimens were removed from the molds and placed in a water bath until the testing days.

Table 6: Mixing proportion of each mixture

ID. mixture	FA (g)	OPC (g)	SH (g)	SH concentration (M)	Hydrated water (g)	Extra water (g)	Sand/ (FA+OPC)	Curing temperature (°C)
MO1	225	25	90	8	10	21.25	2.75	25
MO2	225	25	90	10	10	21.25	2.75	60
MO3	225	25	90	12	10	21.25	2.75	100
MO4	200	50	80	8	20	21.25	2.75	60
MO5	200	50	80	10	20	21.25	2.75	100
MO6	200	50	80	12	20	21.25	2.75	25
MO7	175	75	70	8	30	21.25	2.75	100
MO8	175	75	70	10	30	21.25	2.75	25
MO9	175	75	70	12	30	21.25	2.75	60

Compressive strength of mortar specimens was measured at 7-day age and 28-day age in accordance with ASTM C 109 (ASTM, 2005). Each result of the compressive strength was reported as the average of three specimens. Next, Taguchi analysis was conducted on the results of experiments to determine the optimal mixture condition (the dosage of OPC, the concentration of SH, and the curing temperature). Then, the analysis of variance (ANOVA) was used to identify the percent contribution of each factor on the compressive strength.

3. Results and discussions

Fig. 1 shows the compressive strength of nine geopolymer mortars at 7-day and 28-day age.

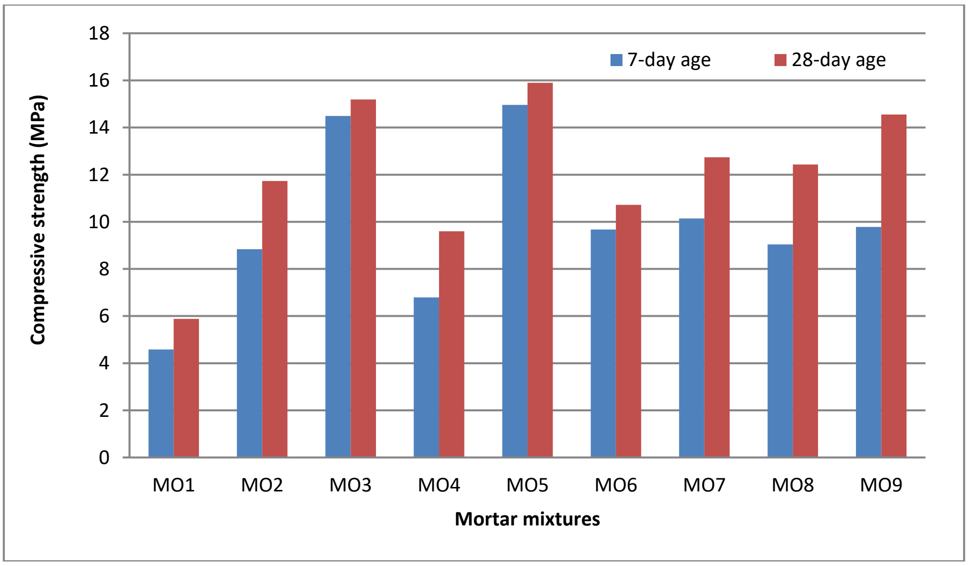

Fig. 1: The compressive strength of geopolymer mortars at 7- and 28-day age

According to Fig. 1, the compressive strength of geopolymers increased slightly with the increase of time. Indeed, an increase of 28-day compressive strength was 4.83% in comparison with 7-day compressive strength in MO3 samples; and an increase of 28-day compressive strength was 6.28% in comparison with 7-day compressive strength in MO5 samples. It can be drawn that the strength development of geopolymer mortars was unlike OPC mortars, which increase about 20% to 30% from 7-day age to 28-day age.

3.1. Analysis of the SNR

3.1.1. 7-day compressive strength

The analysis of SNR has provided the effects of each influencing factor on the 7-day compressive strength, as listed in Table 7 and Table 8. The goal of this study was to maximize the compressive strength of mortars so Eq. 4 (larger is better) was used to analyze the SNR in this study.

Table 7: The results of 7-day compressive strength (R7), 28-day compressive strength (R28) and SNR values

Experiment no.	Control factors			R7 (MPa)	SNR for R7	R28 (MPa)	SNR for R28
	A	B	C				
1	10	8	25	4.58	13.2173	5.88	15.3875
2	10	10	60	8.84	18.9290	11.73	21.3860
3	10	12	100	14.49	23.2214	15.19	23.6312
4	20	8	60	6.79	16.6374	9.60	19.6454
5	20	10	100	14.96	23.4986	15.90	24.0279
6	20	12	25	9.67	19.7085	10.72	20.6039
7	30	8	100	10.14	20.1208	12.74	22.1034
8	30	10	25	9.04	19.1234	12.43	21.8894
9	30	12	60	9.78	19.8068	14.55	23.2573

Table 8: Response table of SNR (larger is better) for R7 and R28

Levels	R7 (MPa)			R28 (MPa)		
	Factor A	Factor B	Factor C	Factor A	Factor B	Factor C
Level 1	18.46	16.66	17.35	20.13	19.05	19.29
Level 2	**19.95**	20.52	18.46	21.43	22.43	21.43
Level 3	19.68	**20.91**	**22.28**	**22.42**	**22.50**	**23.25**
Delta	1.49	4.25	4.93	2.28	3.45	3.96
Rank	3	2	1	3	2	1

It is noted that the highest value of SNR for each factor exhibits the best level of this factor for maximum compressive strength. Thus, the mortar prepared by 20% of OPC (level 2), SH of 12 M concentration (level 3), and 100°C of curing temperature (level 3) attained the optimal value of 7-day compressive strength (Fig. 2).

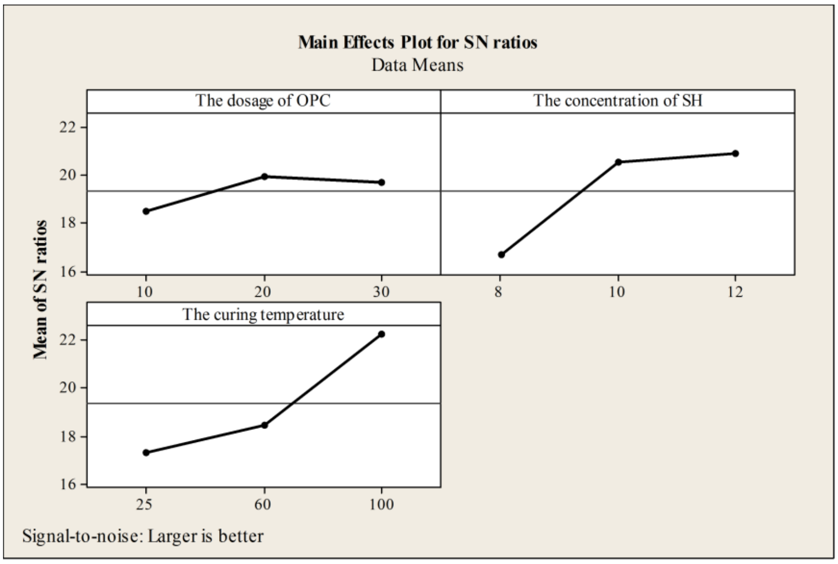

Fig. 2: Effect of control factors on average SNR for R7

Fig. 3 reveals that the 7-day compressive strength grew with increasing the amount of OPC replacement in the mortar mixtures. Using partial OPC in geopolymer mixtures resulted in the formation of both geopolymeric gels (C-(A)-S-H, N-A-S-H) and calcium silicate hydrated (C-S-H) gel (Suwan and Fan, 2014). This has created a strength improvement of geopolymers. The highest compressive strength of specimens cured at a temperature below 70°C attained approximately 8 MPa (Fig. 3). However, there was a strength reduction when the dosage of OPC in the mixtures exceeded the optimal level (20%). This situation may be due to the presence of C-S-H gel, leading to retard the formation of geopolymeric gel (Tailby and Mackenzie 2010).

Furthermore, the curing condition affected the compressive strength significantly. As can be seen in Fig. 3, the lack of heat available led to the low strength of ambient-treatment geopolymers. Many previous works in literature have proved that the temperature increase created a gain of mechanical strength (Atis et al., 2015; Pangdaeng et al., 2014; Rovnaník, 2010). The 7-day compressive strength of samples in this study reached in the range of 10 MPa to 12 MPa for specimens cured at 80°C. And, 14 MPa of compressive strength was observed in the mixtures cured at 100°C. In addition, increasing SH concentration in the geopolymer also improved its compressive strength slightly. A high SH concentration dissolves more fly ash than a low SH concentration leading to a high level of geopolymeric formation. Similar results were observed in some research (Guo et al., 2010; Somna et al., 2011).

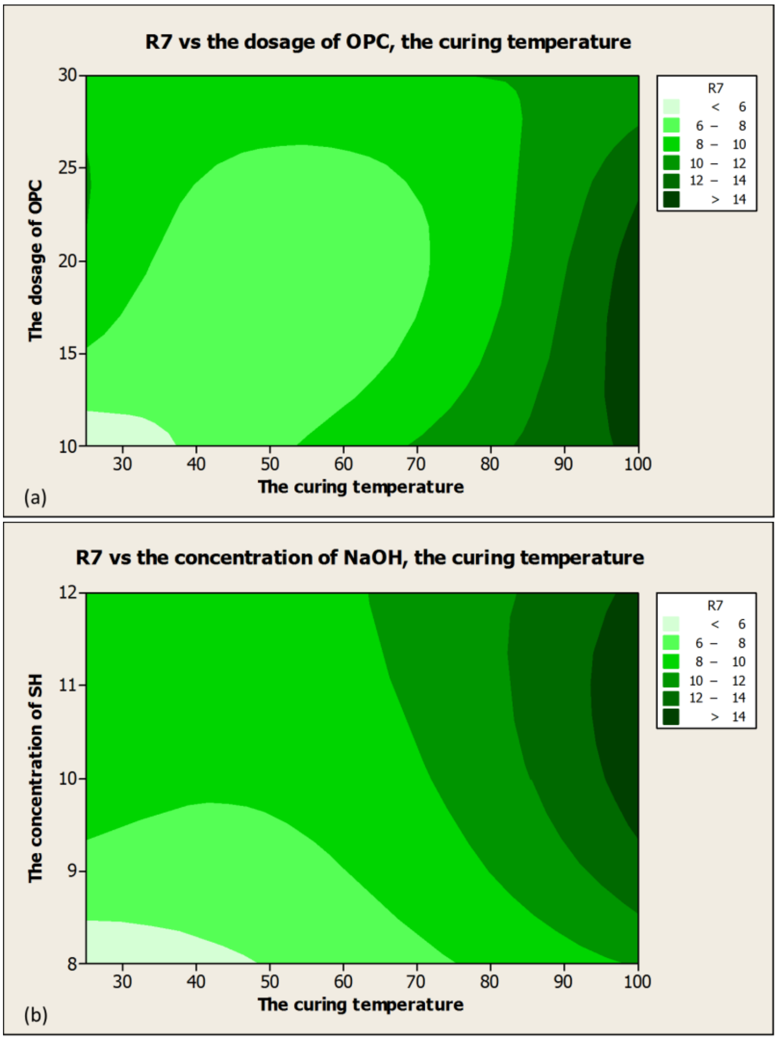

Fig. 3: Effect of control factors on the 7-day compressive strength

3.1.2. 28-day compressive strength (R28)

As can be seen in Fig. 4, the best compressive strength at 28-day age was obtained in the mixture containing 30% of OPC (level 3) and SH of 12 M concentration (level 3) and cured 100°C (level 3). Similar to 7-day compressive strength, the response table of SNR (Table 8) showed that the greatest impact on the compressive strength of geopolymer mortar was the curing temperature. Meanwhile, it was found that the concentration of SH was the second important factor (rank 2), deciding the compressive strength. Fig. 5 indicates that a high concentration of SH produced a high strength of mortars. SH with higher concentration provided a higher dissolving ability leading to an increase in the geopolymerization process, thereby improving the compressive strength (Mishra et al., 2008; Wang et al., 2005). Furthermore, it was observed that OPC in terms of strength contribution at 28 days is better than that of strength contribution at 7 days due to the formation of calcium silicate hydrate (C-S-H) increased with the increase of time.

3.2. Analysis of variance (ANOVA)

In this work, ANOVA providing the measure of confidence was used to analyze the effects of the dosage of OPC, the concentration of SH, and the curing temperature on the compressive strength. This analysis was evaluated at a 95% confidence level and a 5% significance level. Table 9 indicates the ANOVA of the experimental results. It was found that the most influencing factor on both of the 7-day compressive strength and the 28-day compressive strength was the curing temperature. The percent contributions of A, B, and C factors on the 7-day compressive strength were observed to be 2.50%, 36.47%, and 60.49%, respectively. According to Table 9, P values of factor B (the concentration of SH) and factor C (the curing temperature) were lower than 0.05 that means both of the concentration of SH and the curing temperature significantly affected on the compressive strength.

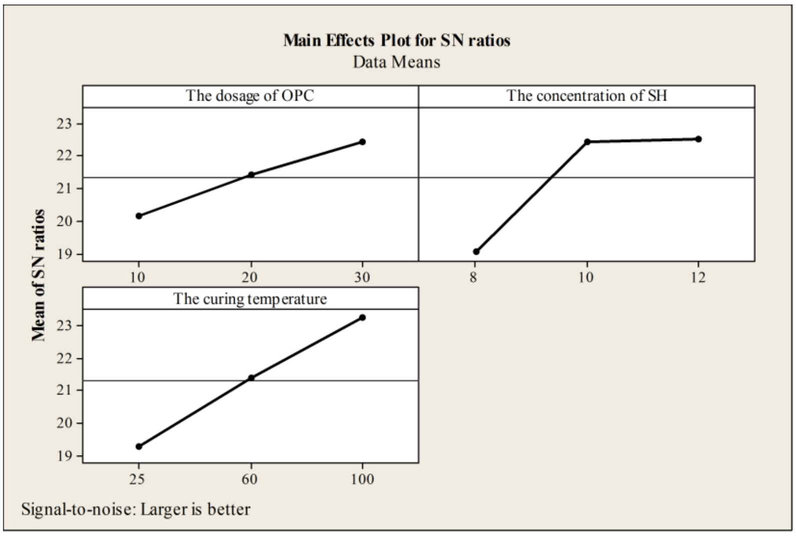

Fig. 4: Effect of control factors on average SNR for 28-day compressive strength

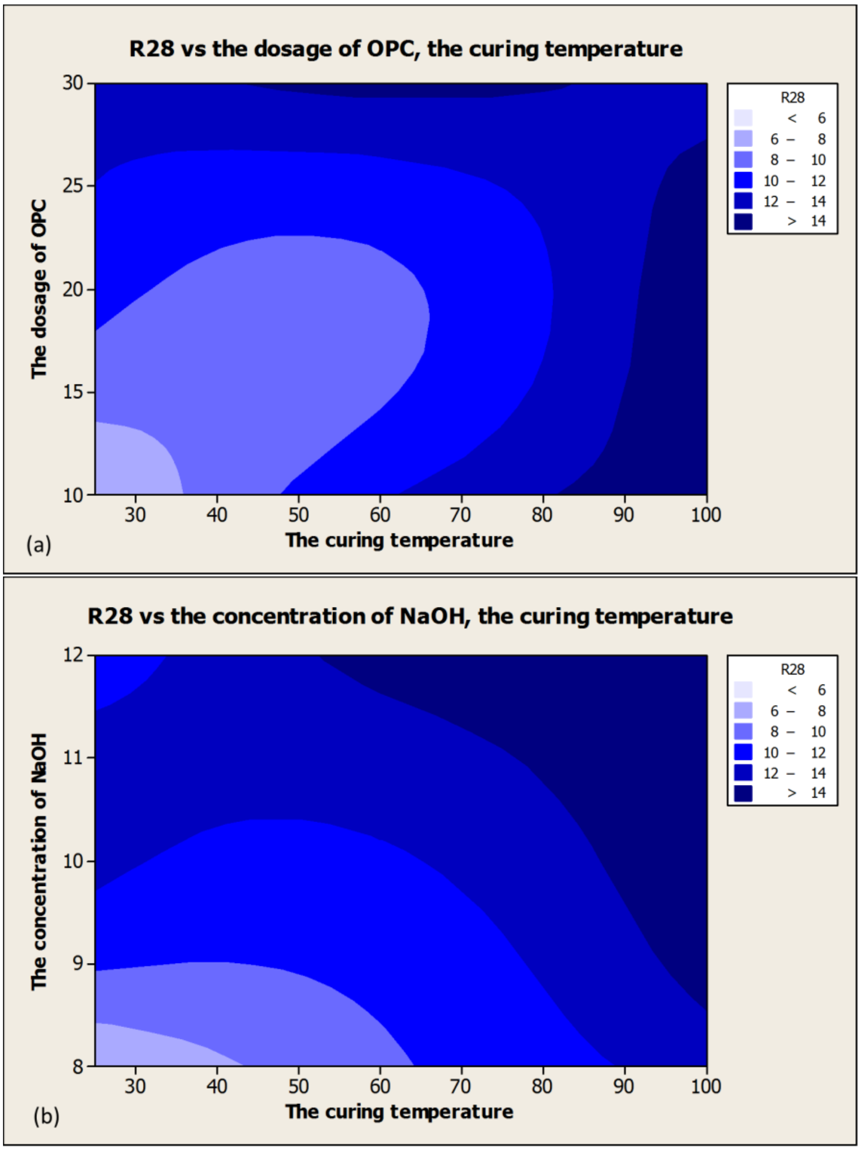

Fig. 5: Effect of control factors on the 28-day compressive strength

Table 9: Results of ANOVA analysis for R7 and R28

Variation of source	Degree of freedom (DF)	Sum of squares (SS)	Mean of squares (MS)	F ratio	P value	Contribution (%)
		7-day compressive strength (R7)				
The dosage of OPC	2	2.164	1.082	4.60	0.179	2.50
The concentration of SH	2	31.565	15.782	67.04	0.015	36.47
The curing temperature	2	52.362	26.181	111.20	0.009	60.49
Error	2	0.471	0.235			0.54
Total	8	86.561				
		28-day compressive strength (R28)				
The dosage of OPC	2	7.981	3.991	11.56	0.080	10.30
The concentration of SH	2	32.240	16.120	46.71	0.021	41.61
The curing temperature	2	36.574	18.287	52.98	0.019	47.20
Error	2	0.690	0.345			0.89
Total	8	77.486				

Besides, the percent contributions of the dosage of OPC, the concentration of SH, and the curing temperature on the 28-day compressive strength were obtained at 10.30%, 41.61%, and 47.20%, respectively. Similar to 7-day compressive strength, the curing temperature was the most important factor influencing significantly on the 28-day compressive strength. And the P-value of the dosage of OPC is over 0.05 that means the dosage of OPC was less effect on the compressive strength.

3.3. Estimation of optimum compressive strength at 7-day and 28-day age

Eqs. 5 and 6 were used to estimate the optimum value of 7-day compressive strength and the optimum value of 28-day compressive strength.

$$R7_{opt} = (A_2 - T_{R7}) + (B_3 - T_{R7}) + (C_3 - T_{R7}) + T_{R7} \quad (5)$$

$$R28_{opt} = (A_3 - T_{R28}) + (B_3 - T_{R28}) + (C_3 - T_{R28}) + T_{R28} \quad (6)$$

where A_2, B_3, C_3 represent the average values of the optimum level of R7, and A_3, B_3, C_3 represent the average values of the optimum level of R28, as listed in Table 10.

T_{R7}=9.810 is the average value of all experimental values of 7-day compressive strength; T_{R28}=12.082 is the average value of all experimental values of 28-day compressive strength.

As a result, the optimum value of 7-day compressive strength was estimated to be 15.363 MPa, and the optimum value of 28-day compressive strength was estimated to be 17.173 MPa.

Table 10: Mean response table for R7 and R28

Levels	R7 (MPa)			R28 (MPa)		
	Factor A	Factor B	Factor C	Factor A	Factor B	Factor C
Level 1	9.303	7.170	7.763	10.933	9.407	9.677
Level 2	**10.473**	10.947	8.470	12.073	13.353	11.960
Level 3	9.653	**11.313**	**13.197**	**13.240**	**13.487**	**14.610**
Delta	1.170	4.143	5.433	2.307	4.080	4.933
Rank	3	2	1	3	2	1

3.4. Confirmation experiment

Table 11 shows the comparison of the experimental values, and the predicted values were obtained by using the Taguchi method. The good agreement between the predicted strength and the actual strength was observed. In other words, the experimental results confirmed the prior design and analysis for optimizing the compressive strength. The compressive strength of geopolymer mortars at 7-day and 28-day was greatly improved through the approach.

Table 11: Predicted values by Taguchi method and confirmation testing values

Level	For Taguchi method		
	Confirmation testing value	Predicted value	Error (%)
7-day compressive strength			
$A_2B_3C_3$ (Optimum)	15.09	15.363	1.81
$A_1B_2C_3$ (Random)	13.53	13.827	2.19
28-day compressive strength			
$A_3B_3C_3$ (Optimum)	16.62	17.173	3.33
$A_1B_2C_3$ (Random)	14.68	14.732	0.35

4. Conclusion

The following conclusions can be drawn from the results of this research:

- Taguchi method could be an effective method to optimize the compressive strength of geopolymer mortars.
- The amount of OPC in geopolymers was the least significant factor that affected on the compressive strength. It was found that the contribution of OPC was 2.5% in terms of compressive strength. Furthermore, the influence of OPC will be enhanced in the long term. Indeed, the contribution of OPC on the compressive strength at 28-day age was 10.30%.

- The most important parameter affected on the compressive strength of geopolymer mortars is the curing temperature. The curing temperature contributed 60.49% to the 7-day compressive strength and 47.20% to the 28-day compressive strength.
- It was predicted that the maximum value of 7-day compressive strength was obtained in the mixture prepared by 20% of OPC content, SH of 12 M concentration, and cured at 100^{o}C. While the mixture produced from 30% of OPC content, SH of 12 M concentration and cured at 100^{o}C created the maximum value of 28-day compressive strength.
- The compressive strength of geopolymer mortars improved slightly from 7-day age to 28-day age.

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Compliance with ethical standards

Conflict of interest

The authors declare that they have no conflict of interest.

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