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Optimization of non-autoclaved aerated concrete using phosphogypsum of industrial waste based on the taguchi method

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Abstract. Phosphogypsum as industrial waste from phosphoric acid production has great potential as a material of added materials of concrete. Optimum composition of gypsum content can increase the compressive strength and setting time of concrete, so it is suitable for use as a non-autoclaved aerated concrete. The experimental design of non-autoclaved aerated concrete manufacture in this study using the Taguchi method. Characteristic of the Taguchi method used is Higher is Better, with controlled factors including the composition of Portland cement, phosphogypsum, and quicklime. ANOVA test results stated that portland cement, phosphogypsum, and quicklime have a significant effect on the compressive strength of non-autoclaved aerated concrete. The results showed that the optimum composition of lightweight concrete was portland cement by 34%, phosphogypsum by 35% and quicklime by 10% to obtain an optimum compressive strength value of 20.93 kg/cm² with a density of 806 kg/m³. The use of phosphogypsum in the manufacture of non-autoclaved aerated concrete can be a solution to reduce the amount of untreated industrial waste.

Keywords: phosphogypsum, non-autoclaved aerated concrete, Taguchi method

1. Introduction

Lightweight concrete needs increase as urban buildings are built higher and thus require lightweight materials. In addition, lightweight concrete is more economical, easier on transportation and enhances seismic capability [1]. Aerated concrete is a lightweight concrete type with several advantages such as low density, lower thermal conductivity and good on sound absorption. Pores of lightweight concrete formed up to 80% due to the reaction of aluminium with lime so as to produce hydrogen gas and form air bubbles that are distributed to all parts of the concrete [2]. Non-autoclaved aerated concrete compared to autoclaved aerated concrete is easier in manufacturing because it does not require high pressure to reduce production costs [3].

Phosphogypsum is a chemical as a by-product of phosphoric acid fertilizer production. The amount of by-products is quite large because every a ton of phosphoric acid will produce a 4.5 tons phosphogypsum [4]. Phosphogypsum consists of calcium sulphate dihydrate and impurities in the form of phosphate, fluorides, sulphates and organic materials. About 15 % of phosphogypsum are recycled as building materials, cement retarders and others [5]. The use of phosphogypsum as a building material has limitations due to impurities such as P₂O₅, fluorides and alkalines [6]



Phosphogypsum has been used in the manufacture of hollow blocks [6], self-level mortar [7] and concrete [8]. Yang *et al.* [5] state that phosphogypsum can be used as a raw material of non-autoclaved aerated concrete, phosphogypsum acts as both an activator and a filler. In addition to phosphogypsum, fly ash [3] and quicklime [5] can also increase the compressive strength of non-autoclaved aerated concrete. So these materials have great potential in making lightweight concrete

The optimum composition of Portland cement, phosphogypsum, and quicklime on the manufacture of non-autoclaved aerated concrete determined to obtain the maximum compressive strength of concrete. Traditional experimental designs are too complex and the number of experiments will be more and more along with the many parameters being studied [9]. In this study using the Taguchi method, that makes it possible to obtain optimal conditions with a fewer number of experiments [10]. The Taguchi method is a effective method to design optimization for quality [11], which is used to find optimal compositions of non-autoclaved aerated concrete from phosphogypsum. The Taguchi method improve the quality of product by optimize the performance characteristics through the setting of design parameters and reduce the sensitivity of the system performance to source of variation [11].

2. Experimental Procedure

2.1. Materials and Methods

The materials used in this study consist of Semen Gresik Portland Cement, phosphogypsum waste from by-products of phosphoric acid production of the local company, fly ash, quicklime, sodium sulphate, sodium silicate, and aluminium powder. The composition of phosphogypsum which determined by X-ray fluorescence shown in Table 1. Non-autoclaved Aerated concrete is made by mixing dry materials (Portland cement, phosphogypsum, fly ash and quicklime) for 1 minute. After stirring the dry material, add water, sodium sulphate, and sodium silicate into the dough and stir for 1 minute until all the ingredients become homogeneous. The aluminium powder as a foaming agent is added to the dough and stir for 30 seconds then mould. Non-autoclaved aerated concrete is removed from the mould after 5 hours. Concrete steam for 12 hours with $\pm 80^{\circ}\text{C}$ temperature and lightweight concrete cured for 28 days.

Table 1. Composition of Phosphogypsum.

Compound	Si	S	Ca	Ti	Mn	Fe	Ni	Cu	Zn	Sr	Mo	Ba	Re
Concentration Unit (%)	1.2	14.9	72.3	0.22	0.075	0.50	2.70	0.33	0.09	1.4	5.7	0.3	0.2

2.2. Design Experiment

The Taguchi method is used to determine the combination of optimum factors with a small amount of experimentation. In this study selected three controlled factors namely composition of Portland cement, phosphogypsum and quicklime each with three levels to obtain the optimum compressive strength as shown in Table 2

Table 2. Controlled and Uncontrolled Factor.

Level	Controlled Factor			Uncontrolled Factor		
	Portland Cement (%)	Phosphogypsum (%)	Quicklime (%)	Sodium Sulphate (%)	Sodium Silicate (%)	Aluminium Powder (%)
1	26	35	8			
2	30	40	10	1.6	5	0.074
3	34	45	12			

Based on the Taguchi method, experiments with 3 factors and 3 levels must be done with 9 combinations of factors and levels. The combination is shown on the Orthogonal Array in Table 3. The

analysis of the effect of the factors on the compressive strength of lightweight concrete is done with ANOVA, while the optimum combination is determined by Signal to Noise Ratio (SNR) with characteristic higher is better, which calculate by equation 1. SNR is tool in Taguchi method to find best level for each composition or factor so as to maximize SNR [12].

$$SNR = -10 \log_{10} \left[\frac{1}{n} \sum_{i=1}^n \frac{1}{y_i^2} \right] \quad (1)$$

Table 3. Orthogonal Array

Run	Controlled Factor		
	Portland Cement (%)	Phosphogypsum (%)	Quicklime (%)
1	26	35	8
2	26	40	10
3	26	45	12
4	30	35	10
5	30	40	12
6	30	45	8
7	34	35	12
8	34	40	8
9	34	45	10

3. Results and Discussion

The non-autoclaved aerated concrete was prepared according to the composition specified on the orthogonal array with 4 replicates every run. The results of the compressive strength test are shown in Table 4.

Table 4. Compressive Strength of Concrete

Run	Compressive Strength (kg/cm ²)				Average of Compressive Strength (kg/cm ²)
	1	2	3	4	
1	10	10.8	8.8	11.6	10.3
2	9.2	10	8.4	11.6	9.8
3	11.2	11.2	10.8	10.4	10.9
4	15.2	13.6	17.2	16.4	15.6
5	10	9.2	11.2	13.2	10.9
6	9.6	8	9.2	9.6	9.1
7	11.6	18.4	12.4	14.8	14.3
8	14	12.4	14.4	14.8	13.9
9	11.6	14.4	10	14.4	12.6
Average					11.9

ANOVA test in this research is done to know the influence on each factor to the compressive strength of non-autoclaved aerated concrete. The initial hypothesis on ANOVA test calculation is given as follows:

- H0: $\tau_1 = \tau_2 = 0$ (factor has no significant effect on compressive strength of non-autoclaved aerated concrete)
 - H1: $\tau_1 \neq 0$ (factor has significant affecting on compressive strength of non-autoclaved aerated concrete)
- H0 will be rejected if the value of F-Value > F table.

Table 5. Analysis of variance

Source	DF	Adj SS	Adj MS	F-Value	F-Table
Portland Cement (A)	2	64.107	32.053	21.84	3.28
Phosphogypsum (B)	2	41.387	20.693	14.10	3.28
Quicklime (C)	2	14.907	7.453	5.08	3.28
Error	29	42.560	1.4676		
Total	35	162.960			

Table 5 shows that the Portland cement, phosphogypsum, and quicklime factors have F-Value > F-Table so that H0 is rejected and it can be said that all controlled factors have a significant effect on the compressive strength of lightweight concrete. The compressive strength of concrete increases with the increase of Portland cement content in concrete, this is because a large amount of cement will encourage the formation of more bonds gel [13, 14].

The composition of phosphogypsum has a significant effect on the compressive strength of lightweight concrete. Compressive strength of concrete with age of 28 days decreased along with an increasing amount of phosphogypsum [15, 16]. Phosphogypsum acts as a filling material in concrete and only a few phosphogypsum follow in the hydration reaction [17].

The composition of quicklime has a significant effect on compressive strength, the addition of lime content increases the compressive strength and density of lightweight concrete as it produces a solid structure. Tian *et al.* [17] in his research revealed that compressive strength can increase 408% with the addition of a percentage of quicklime.

The optimum composition is obtained by calculating SNR with equation 1, the SNR value of each run is shown in Fig. 1. SNR gives the parameter level combination with minimum standard deviation while keeping the mean on target [18]. Level 3 of Portland cement factor has the highest SNR value 22.67, it shows the optimum composition of Portland cement is at level 3 in 34%. The highest SNR of phosphogypsum factor is 22.43 in level 1, which means the optimum composition phosphogypsum is at level 1 in 35%. Finally, the factor of quicklime has the highest SNR of 21.90 in level 2, which means the optimum quicklime is at level 2 in 10%.

The average compressive strength at each factor and level in Fig. 2 show that the optimum Portland cement in level 3 can produce 13.6 kg/cm² concrete. The phosphogypsum in level 1 can produce a compressive strength of 13.4 kg/cm², and quicklime of 12.67 kg/cm² 3 in level 2. Average compressive strength value is used to predict the compressive strength generated by the optimum composition, using the formula in equation 2.

$$\begin{aligned}
 \text{compressive strength prediction} &= A\bar{3} + B\bar{1} + C\bar{2} - 2(\text{Average}) \\
 &= 13.60 + 13.40 + 12.67 - (2 \times 11.93) \\
 &= 15.99 \text{ kg/cm}^2
 \end{aligned} \tag{2}$$

The above formula calculation results show that the prediction of the compressive strength of non-autoclaved aerated concrete with combination of optimum factor level is 15.99 kg/cm².

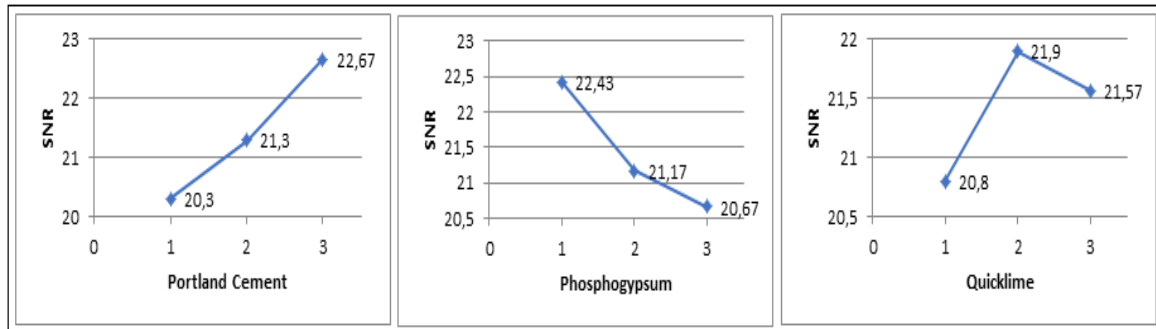


Figure 1. SNR value of each factor and level.

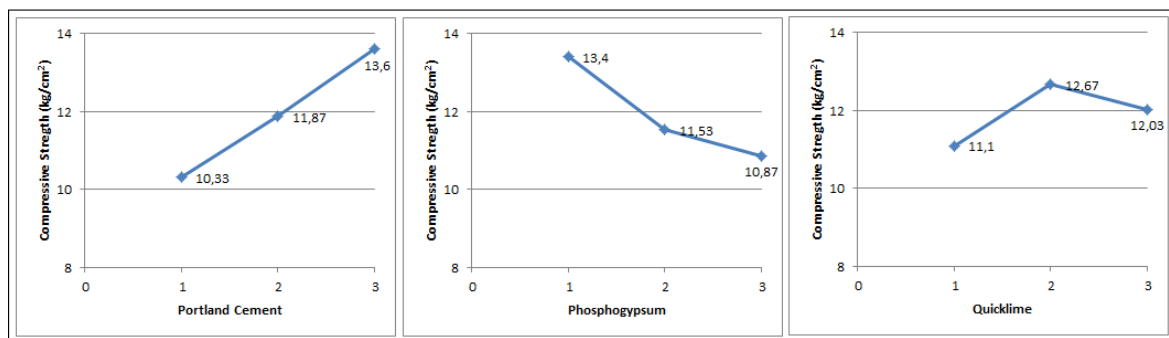


Figure 2. The average compressive strength of each factor and level.

The optimum composition is not on the orthogonal array, so the non-autoclaved aerated concrete is made according to the optimum composition obtained from SNR calculation. The result of compressive strength on 3 replication of concrete showed in Table 6 so that the average compressive strength is 20,93 kg/cm². The average yield of compressive strength is greater than the predicted value of 15.99 kg/cm². The density of non-autoclaved aerated concrete on optimum composition is 806 kg/m³ complies with lightweight concrete.

Table 6. Compressive Strength of Optimum Run.

Run	Controlled Factor			Compressive Strength (kg/cm ²)			Average Compressive Strength (kg/cm ²)
	Portland Cement (%)	Phosphogypsum (%)	Quicklime (%)	1	2	3	
Optimum Run	34	35	10	20	22.8	20	20.93

Optimum concrete with compressive strength value of 20.93 kg/cm² and the 806 kg/m³ density in this study has entered the standard including ASTM C1386-07 AAC lightweight concrete with strength class II category where the minimum compressive strength value is 20 kg/cm². Lightweight concrete with that compressive strength values according to Neville and Brooks [19] can be used as lightweight insulating concrete.

4. Conclusions

Based on the result of the research, the conclusions are the Portland cement, phosphogypsum, and quicklime have a significant effect on the compressive strength of non-autoclaved aerated concrete. The

optimum composition of non-autoclaved aerated concrete in this study was Portland cement by 34%, phosphogypsum by 35% and quicklime by 10%. The compressive strength of the optimum composition non-autoclaved aerated concrete was 20.93 kg/cm² and density of 806 kg/m³.

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