# Optimization Density of Geopolymer Concrete based on Taguchi Method

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***Abstract***
*High density geopolymer concrete can be applied as a breakwater because this particular material is able to break high sea waves and is not easily carried by them. Geopolymer concrete is composed of fly ash, sodium silicate, and activator solution. The Taguchi method can be used to determine the factors that affect the density of geopolymer concrete, as well as the optimum composition that can produce the highest density. Controlled factors in this study were a silica/alumina ratio, solid/liquid ratio, sodium hydroxide concentration and aggregate type.*

*The results of this study indicate that the ratio of silica/alumina, solid/liquid ratio, and type of aggregate has a significant effect on the density of geopolymer concrete. The optimum composition of geopolymer concrete is silica/alumina 9, solid/liquid 70:30, sodium hydroxide concentration of 6 M and aggregate type of granite yielding the density of 2,41 gram/cm$^3$ and 21 MPa compressive strength.*

**Keywords:** Geopolymer concrete, density, Taguchi method.

## Introduction
Fly ash is a side-product of coal combustion which is mechanically or electrostatically separated[1]. Fly ash has the primary content of silica and alumina with various shapes and sizes[2]. Based on Government Regulation of the Republic of Indonesia No. 18 of 1999, fly ash falls into the category of hazardous and toxic substances waste, and must be handled appropriately. The large silica content of fly ash makes this material suitable for use as a mixture of concrete[3], paving[4], lightweight concrete[5] and geopolymers[6]. The application of fly ash as an added material in the synthesis of concrete can increase the compressive strength of concrete and lowering the water/binder ratio[7].

Geopolymer is an inorganic material that is synthesized from alumina-silica gel in an alkaline environment. The geopolymer microstructure consists of chains and networks of inorganic molecules that are covalently bonded[8]. Geopolymer can be synthesized from rice husk ash[9], bottom ash[10] or fly ash[6]. Geopolymers include environmentally-friendly materials, since they do not require high-temperature combustion, thus saving energy and reducing carbon dioxide emissions. Geopolymer concrete has a better compressive strength compared to conventional concrete. Bagci et al[11] synthesized a geopolymer with a compressive strength reaching 24.8 MPa.

The results of Chindaprasirt et al[12] demonstrate that the compressive strength of a geopolymer is influenced by activator molarity, and the increase in activator concentration causes an increase in the resulting compressive strength of the geopolymer. Meanwhile, Setiadji[13] revealed that compressive strength is influenced by the ratio of activators to the fly ash, and the ratio of the geopolymer paste to the aggregate. Curing also has an influence on the compressive strength of the geopolymer; a longer curing time will increase the compressive strength[14].

The high compressive strength of the geopolymer makes this type of concrete suitable for use as a breakwater, as geopolymers also have a high sulfate resistance[15] that can be applied in sea water. Bayuaji et al[16] revealed that curing geopolymers in sea water produces geopolymers with a higher compressive strength compared to curing in fresh water. In addition to these properties, geopolymers in their application as breakwater must have a high density so that the concrete is not easily carried by sea waves.

The determination of the raw material composition that can produce the optimum density of the geopolymer is carried out by design of experiment-Taguchi method. The Taguchi method is a principled design method of quality improvement by minimizing the effects of variation, but without eliminating the cause[17]. Optimized experimental factors are calculated based on Signal to Noise Ratio (SNR) derived from the Taguchi approach shortened number of experimental factors with noticeable improvment in density of the geopolymer[18].

In addition to the optimum composition, this method will make known the controlled factors that significantly affect the geopolymer density. Controlled factors in this research are silica/alumina ratio, solid/liquid ratio, concentration of activator and type of aggregate. Synthesis and optimization of high density geopolymer based on the Taguchi method have great potential for efficient time savings and strategies to optimize the synthesis condition.

Based on the background, this study aims to determine the factors that have a significant effect on the density of geopolymer concrete, and to determine the optimum geopolymer composition that can produce the highest compressive strength.

## Material and Methods

**Materials:** Geopolymers are synthesized from coal-burned fly ash from the local industry, sodium hydroxide solution from NaOH pellets Merck 98%, sodium silicate and three types of aggregates.

**Methods:** The sodium hydroxide solution is added with sodium silicate and mixed with fly ash to form a geopolymer paste. The already formed geopolymer paste is then added to the aggregate used. The mixing of the geopolymer paste with the aggregate serves to form a geopolymer concrete material. The geopolymer concrete is then casting and cured at room temperature.

**Design of Experiment based on Taguchi Method:** The Taguchi method was used to design the experiment and achieve the optimum density of the geopolymer. Taguchi is a factorial design that uses orthogonal arrays (OAs) to estimate how various factors have affect the density. This study aims to produce geopolymer concrete that has the highest density. Controlled factors in this research are silica/alumina ratio, solid/liquid ratio, sodium hydroxide concentration and type of aggregate. The factors and levels used in this study are shown in table 1.

The $L_9$ OA presents the minimum number of experiments to be performed with 4 factors and 3 levels and is shown in table 2.

**Table 1**
**Factors and Levels**

| Level | Factor | | | |
|---|---|---|---|---|
| | Silica/ Alumina | Solid/ Liquid | NaOH (M) | Aggregate |
| -1 | 8 | 60:40 | 6 | Kediri sand |
| 0 | 8.5 | 70:30 | 10 | Bojonegoro sand |
| +1 | 9 | 80:20 | 14 | Granite |

**Table 2**
**Orthogonal Array**

| Run | Silica/ Alumina | Solid/ Liquid | NaOH (M) | Aggregate |
|---|---|---|---|---|
| 1 | 8 | 60:40 | 6 | Kediri sand |
| 2 | 8 | 70:30 | 10 | Bojonegoro sand |
| 3 | 8 | 80:20 | 14 | Granite |
| 4 | 8.5 | 60:40 | 10 | Granite |
| 5 | 8.5 | 70:30 | 14 | Kediri sand |
| 6 | 8.5 | 80:20 | 6 | Bojonegoro sand |
| 7 | 9 | 60:40 | 14 | Bojonegoro sand |
| 8 | 9 | 70:30 | 6 | Granite |
| 9 | 9 | 80:20 | 10 | Kediri sand |

The calculation of combinations of factors and levels was performed to determine the composition that can produce the highest density. This is carried out by calculating the value of Signal to Noise Ratio (SNR) in equation 1. The highest SNR shows that factor and level can produce the optimum density of the geopolymer.:

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

## Results and Discussion

Among the main characters of breakwater is having a high density so that the breakwater concrete is not carried away by the ocean water currents. In addition, it has a high enough compressive strength to withstand pressure on the ocean wave currents. The result of the density test for each sample is shown in table 3.

**Table 3**
**Result of density Test**

| Run | Density (gram/cm$^3$) | | | | Average Density (gram/ cm$^3$) |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | |
| 1 | 2.11 | 2.13 | 2.12 | 2.13 | 2.12 |
| 2 | 2.31 | 2.28 | 2.30 | 2.29 | 2.30 |
| 3 | 2.12 | 2.15 | 2.13 | 2.14 | 2.13 |
| 4 | 2.27 | 2.18 | 2.19 | 2.28 | 2.23 |
| 5 | 2.14 | 2.04 | 2.12 | 2.00 | 2.07 |
| 6 | 2.04 | 1.98 | 1.98 | 2.04 | 2.01 |
| 7 | 2.31 | 2.25 | 2.28 | 2.32 | 2.29 |
| 8 | 2.42 | 2.40 | 2.40 | 2.43 | 2.41 |
| 9 | 1.90 | 1.93 | 1.93 | 1.89 | 1.91 |

The analysis of variance (ANOVA) was performed to determine the effect of each factor on the composition used on the density of geopolymer concrete. The calculation of analysis of variance uses the following hypotheses:

- **H0**: The factor has no effect on the density of geopolymer concrete.
- **H1**: Factors affecting the density of geopolymer concrete.

The initial hypothesis is rejected if the F-Value value> F α, df-num, df-den. Based on the distribution table, F for (0.05, 2, 33) is 3.28. The results of ANOVA are listed in table 4.

The results in table 4 show that the silica/alumina ratio has a significant effect on the density of the geopolymer. Silika is a compound that has strong and hard properties[19], and these properties can affect the density of the geopolymer. In silica, the pores within the granules can be filled to prevent the growth of excess grains makeing the resulting density higher[20]. Meanwhile, alumina is a nonmagnetic material that can provide additional pores if added, and can also affect the density[21]. Meilyana[22] states that the reduction of alumina percentage can cause a value of depreciation and increased density because it is followed by a decrease in the value of porosity.

**Tabel 4**
**Result of Analysis Of Variance**

| Source | DF | Adj SS | Adj MS | F-Value | F-Table |
|---|---|---|---|---|---|
| Silica/Alumina | 2 | 0.07 | 0.03 | 28.80 | 3.28 |
| Solid/Liquid | 2 | 0.39 | 0.20 | 171.29 | 3.28 |
| NaOH | 2 | 0.01 | 0.01 | 3.16 | 3.28 |
| Agregat | 2 | 0.32 | 0.16 | 137.83 | 3.28 |
| Error | 27 | 0.03 | 0.01 | | |
| $SS_{total}$ | 35 | 0.82 | | | |

The solid/liquid ratio also has a significant effect on density. Differences in the solid/liquid ratio can produce various geopolymer structures so as to cause different densities[23]. The type of aggregate has a significant effect on the density to be generated on the geopolymer concrete. Aggregate size differences also affect the density and porosity level of geopolymer concrete. A good grain arrangement can produce maximum density and minimum porosity. Sodium hydroxide concentration did not significantly affect the density of geopolymer concrete. The concentration of sodium hydroxide affects the polymerization reaction, thus causing the high compressive strength of the geopolymer, but has no effect on the density.

Table 5 shows the average of SNR every run from equation 1. The average SNR calculation results can be seen in figure 1. The highest SNR of silica/alumina is 6,82 in level 3 which means the optimum ratio of silica/alumina factor is at level 3. The highest SNR of solid/liquid is 7.07 in level 2 which means the optimum ratio of solid/liquid factor is at level 2. Sodium hydroxide factor has the highest SNR of 6.75 in level 1, which means the optimum concentration of sodium hydroxide is in level 1. Finally, the aggregate factor has the highest SNR of 7.06 in level 3, which means the optimum aggregate is in level 3.

The optimum silica/alumina ratio is at level 3 of 9. Jansen and Christiansen[24] obtained the optimum ratio of silica/alumina 9 in the synthesis of mortar geopolymer with 37.9 MPa compressive strength. The optimum solid/liquid ratio is at level 2 with a ratio of 70:30. The composition of the ingredients on the sodium hydroxide factor has an optimum value at level 1 of the concentration of 6 M. The optimum aggregate type at level 3 uses granite. The use of granite can increase the density and the compressive strength, since granite has a rough surface forming stronger bonds.

The average density at each factor and level in figure 2 shows that the optimum silica/alumina in level 3 can produce geopolymer with a density of 2.20 gram/cm$^3$. The solid/liquid in level 2 can produce a density of 2.26 gram/cm$^3$, sodium hydroxide of 2.18 gram/cm$^3$ in level 1, and aggregate of 2.26 gram/cm$^3$ in level 3. Average density value is used to predict the density generated by the optimum composition using the following formula:

$$\rho_{prediction} = A3+B2+C1+D3-(3 \times Ra)$$
$$= 2.20+2.26+2.18+2.26-(3 \times 2.16)$$
$$= 2.39 \text{ gram/cm}^3$$

**Table 5**
**Average of Density and SNR**

| Run | Average of Density (gram/cm$^3$) | Average of SNR |
|---|---|---|
| 1 | 2.12 | 6.53 |
| 2 | 2.30 | 7.22 |
| 3 | 2.13 | 6.58 |
| 4 | 2.23 | 6.97 |
| 5 | 2.07 | 6.34 |
| 6 | 2.01 | 6.06 |
| 7 | 2.29 | 7.20 |
| 8 | 2.41 | 7.64 |
| 9 | 1.91 | 5.63 |
| **average** | 2.16 | 6.69 |

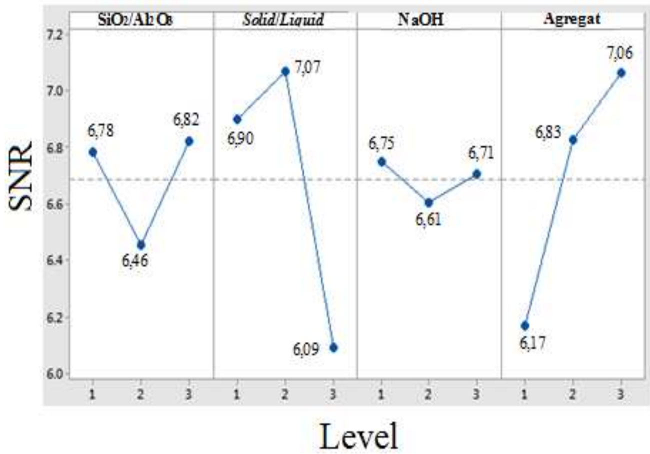

**Figure 1: SNR value of each factor and level**

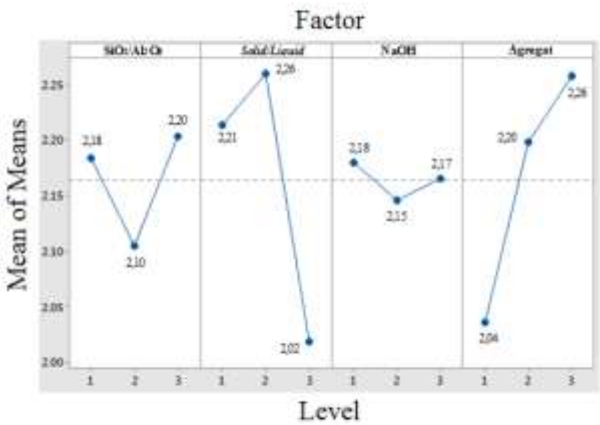

**Figure 2: Density of Each Factor and Level**

In this study, no experiments were conducted to confirm the optimum composition and density prediction since the optimum composition based on the SNR calculation shows that the composition was already present during the $8^{th}$ run. The $8^{th}$ run used the optimum composition of silica/alumina ratio 9, solid/liquid ratio of 70:30, sodium hydroxide concentration of 6 M, and aggregate type with granite. This composition produces geopolymer with a density value of 2.41 gram/$cm^3$ and a compressive strength of 21 MPa. The results are not different from the predicted value of 2.39 gram/$cm^3$, and the value is greater than the average geopolymer density of 2-2.1 gram/$cm^3$.[25]

Allsop[26] mentions that concrete applied as a breakwater has a density above 2.4 gram/$cm^3$. Based on this, the synthesized geopolymer concrete satisfies this requirement. Synthesized geopolymers can be applied as concrete breakwaters, attributable to their high concrete density that is able to withstand waves, and not be carried by them. Meanwhile, the resulting geopolymer compressive strength of 21 MPa has qualified the compressive strength of concrete as a breakwater of 20,7 MPa[27].

## Conclusion

Silica/alumina ratio, solid/liquid ratio, and aggregate type have a significant influence on the density of geopolymers. The optimum composition is silica/alumina ratio 9, solid/liquid ratio 70:30, concentration of sodium hydroxide 6 M and type of aggregate is granite.

## Acknowledgement

The authors wish to thank LPPM UISI for providing *Hibah Riset Bersaing UISI.*

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