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OPTIMASI PROSES PRODUKSI KOMPOSIT AGREGAT TANAH LIAT RINGAN (LECA) KASGOT MENGGUNAKAN METODE TAGUCHI UNTUK MEMPROMOSIKAN TEKNOLOGI AGROINDUSTRI

OPTIMIZATION OF THE PRODUCTION PROCESS OF LIGHTWEIGHT EXPANDED CLAY AGGREGATE (LECA) COMPOSITE KASGOT USING THE TAGUCHI METHOD TO PROMOTE AGROINDUSTRIAL TECHNOLOGY

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Abstract

This study focuses on optimizing the production process of *Lightweight Expanded Clay Aggregate* (LECA) made from composite kasgot material by integrating the Taguchi method, regression analysis, and ANOVA. The main problem in this study is the uncertainty of the quality of LECA made from composite kasgot due to production process parameters that are not yet ideal. In addition, the increase in kasgot waste also encourages the need for more valuable utilization so that the LECA production process must be efficient in order to be optimal, consistent, and environmentally friendly. The Taguchi method was used to determine the most effective combination of production parameters, including combustion temperature, combustion duration, and LECA particle diameter using the L9 experimental design. The analysis results showed that combustion temperature was the most dominant factor, especially in terms of production costs and surface roughness values. The findings of the ANOVA analysis confirm that temperature has a significant effect on most responses, while diameter has a strong effect on LECA mass parameters. A regression model was then constructed to predict the behavior of each response based on process factors. Based on these two methods, the most optimal method was ANOVA with a combustion temperature of 200° C, combustion time of 2 hours, and a diameter of 2 cm. The standard *error* obtained for *cost* was 0, for *roughness* was 0.178, for mass was 53.7, for permeability was 0.235, with a *composite desirability* value of 0.607448.

Keywords: LECA, Kasgot, Taguchi, Regression, ANOVA

Abstract

This research focuses on optimizing the manufacturing process of Lightweight Expanded Clay Aggregate (LECA) made from a mixture of kasgot composites by integrating the Taguchi method, regression analysis, and Anova. The main problem of this research is the uncertainty of the quality of LECA made from kasgot composites due to less than ideal production process parameters. Additionally, the increase in kasgot waste encourages the need for more valuable utilization, so that the LECA production process must be efficient to be optimal, consistent, and environmentally friendly. The Taguchi method is used to determine the most effective combination of production parameters, including firing temperature, firing duration, and LECA grain diameter using the L9 experimental design. The results of the analysis show that firing temperature is the most dominant factor, especially on production costs and surface roughness values. The findings of the ANOVA analysis confirm that temperature has a significant effect on most responses, while diameter has a strong effect on the LECA mass parameter. A regression model is then built to predict the behavior of each response based on process factors. Based on the research of these two methods, the most optimal is the ANOVA method with a firing temperature of 200°C, a firing time of 2 hours, and a diameter of 2 cm. The standard error obtained for cost is 0, for roughness is 0.178, for mass is 53.7, for permeability is 0.235 with a 0 , and the composite desirability value is 0.607448.

***Keywords:** LECA, Kasgot, Taguchi, Regression, ANOVA*

I. INTRODUCTION

Lightweight Expanded Clay Aggregate is a type of manufactured aggregate produced from clay-based materials. The properties and quality of the product depend on the quality of the raw materials, the type of additives used during fabrication, and the production technology applied[1]. *Lightweight Expanded Clay Aggregate* is a lightweight material that is widely used in various fields, especially in the agricultural and construction sectors, making it a major focus in the development and production process [2]. This growing medium is produced from clay material that is formed into balls, creating pores within the structure of the growing medium [3]. Hidroton is another name for LECA and is often used in the agricultural sector because it is lightweight and porous, enabling it to create an optimal drainage system and adequate air space for plant root development [4]. The purpose of this study is to determine the effect of the benefits of kasgot mixture for hidroton and to determine the most optimal production process. If it is proven that this kasgot-mixed hydroton is optimal, then this composite kasgot-mixed hydroton can be an alternative growing medium.

Image 1 Lightweight Expanded Clay Aggregate (Hydroton)

Source: https://pelatihanhidroponik.com

Organic waste, which is easily decomposable, often causes unpleasant odors and has the potential to become a source of disease. If not managed properly, organic waste can accumulate from the collection stage to the disposal process at the final processing site [5]. To address this problem, a strategy for utilizing organic waste that has economic value is needed. One alternative solution that can be applied is through the use of *Black Soldier Flies* (BSF) or *Hermetia illucens*[6]. The ability of BSF to degrade organic waste has been proven effective. *Larvae* (maggots) utilize organic material as a source of nutrition for growth for approximately 25 days until they reach the harvest phase[7]. In addition, BSF larvae contain compounds that are antimicrobial and antifungal[8]. Kasgot or (Bekas Maggot) is a residual material derived from BSF larvae feces and can be used as a planting medium. At the harvesting stage, kasgot is separated from the larvae and then placed in a bucket according to the type of organic waste used[9]. This study was conducted to analyze the effectiveness of kasgot as a growing medium and its application in its use .

Image 2 Kasgot Composite

Source:
https://magalarvasayanaindonesia.web.indotrading.com

In this study, Minitab software was used because Minitab provides comprehensive statistical analysis methods, ranging from descriptive statistics to hypothesis testing and quality analysis, thereby assisting researchers in processing and interpreting data accurately. Minitab software is also frequently used for research purposes[10]. The Taguchi method is a e approach designed to improve product and process quality while minimizing costs and resource usage[11]. This method can only handle one response at a time, so it needs to be combined with other methods to obtain more comprehensive results[12]. The purpose of the Taguchi method is to make products resistant to noise, so this method is often known as *Robust Design*, which is an effort to develop products to improve performance while minimizing the influence of disturbing factors[13]. In the Taguchi method, parameter design is carried out to improve product quality while reducing high variability[14].

The Simple Linear Regression method is used to analyze the relationship between one independent variable and a dependent variable that has a linear relationship. The value obtained from the dependent variable is most likely influenced by the independent variable[15]. The selection of the linear regression method as a prediction tool in this study is based on its ability to estimate simple model parameters and process time series data. In addition, this method allows the use of several independent variables (X), so that the prediction results are more accurate[16]. Linear regression calculations produce equations that can be used as a reference to predict the value of dependent variables in the future by entering the value of the independent variable into the equation[17].

The ANOVA method was introduced by Ronald Fisher as an extension of the t-test, with the advantage of being able to compare more than two groups simultaneously[18]. The ANOVA test is a statistical hypothesis testing method that allows conclusions to be drawn based on data or groups in inferential statistical analysis[19]. The null hypothesis in the ANOVA test states that all samples come from the same population at random, so that the mean and variance of each group are considered to be no different or to have equivalent values[20]. To minimize the effect of data reading errors on the ANOVA analysis results, an evaluation of potential errors is carried out through residual analysis before the ANOVA calculation process is performed [21].

The concept of *smart farming* or precision agriculture focuses on the application of a systematic approach that emphasizes the integrated management of inputs, processes, and outputs as its main objective [22]. Increasing the proportion of maggot residue in LECA raw materials is predicted to reduce density and significantly increase aggregate porosity compared to LECA without maggot residue, in each mixture variation tested. This prediction is supported by the fact that organic materials tend to form more pores during the combustion process. In addition, maggot has good potential as a sustainable alternative in the agricultural and waste management sectors in the future [23].

This study aims to determine the most effective method among Taguchi, ANOVA, and Regression in optimizing the production process of maggot-based composite LECA. Furthermore, this study focuses on finding the most optimal combination of process parameters to produce lightweight aggregates with the best physical, mechanical, and thermal characteristics. These objectives were achieved through the application of Taguchi experimental design, ANOVA analysis, and regression modeling as the basis for product quality evaluation and prediction.

II. LITERATURE REVIEW

Lightweight Expanded Clay Aggregate (LECA) is a lightweight aggregate made from clay that is heated until it expands, producing a porous structure suitable for use in agriculture and construction[24]. The quality of LECA is greatly influenced by the raw materials, additives, and production process parameters used[25]. On the other hand, the increase in organic waste has become a significant environmental problem. Processing technology using *Black Soldier Fly* (BSF) maggots has proven to be effective in decomposing organic waste and producing useful residues, namely kasgot. Kasgot has porous and lightweight physical characteristics, making it potentially usable as a composite material in the manufacture of organic-based LECA.

Minitab in this study functions as statistical software used to process, analyze, and visualize data to support decision making. This software is widely used in research, quality control, and process improvement because it is capable of performing statistical analysis, design of experiments (DOE), regression analysis, hypothesis testing, and graphing quickly and accurately[26].

The Taguchi method is an experimental design method that aims to improve process or product quality by reducing variation due to disturbance factors. This method begins by determining quality characteristics, then setting control factors and their levels[27]. Next, experiments are designed using orthogonal arrays to make the number of trials more efficient. The experimental data is analyzed using the Signal to Noise Ratio (S/N) to obtain the best combination of factors that produces optimal and stable performance[28].

The application of methods such as Taguchi, Regression, and ANOVA analysis offers opportunities to produce more efficient and consistent LECA, supporting sustainable organic waste management within the framework of *smart farming* and agroindustrial technology.

III. RESEARCH METHOD

To clarify the sequence of the research process carried out, the research steps were systematically arranged and presented in the form of a flowchart (Image 3 Research Flowchart). This visualization provides a comprehensive understanding of the research stages, starting from problem formulation, data collection, application of Taguchi, ANOVA, and

Regression analysis methods, to the determination of optimal parameters and interpretation of the final results.

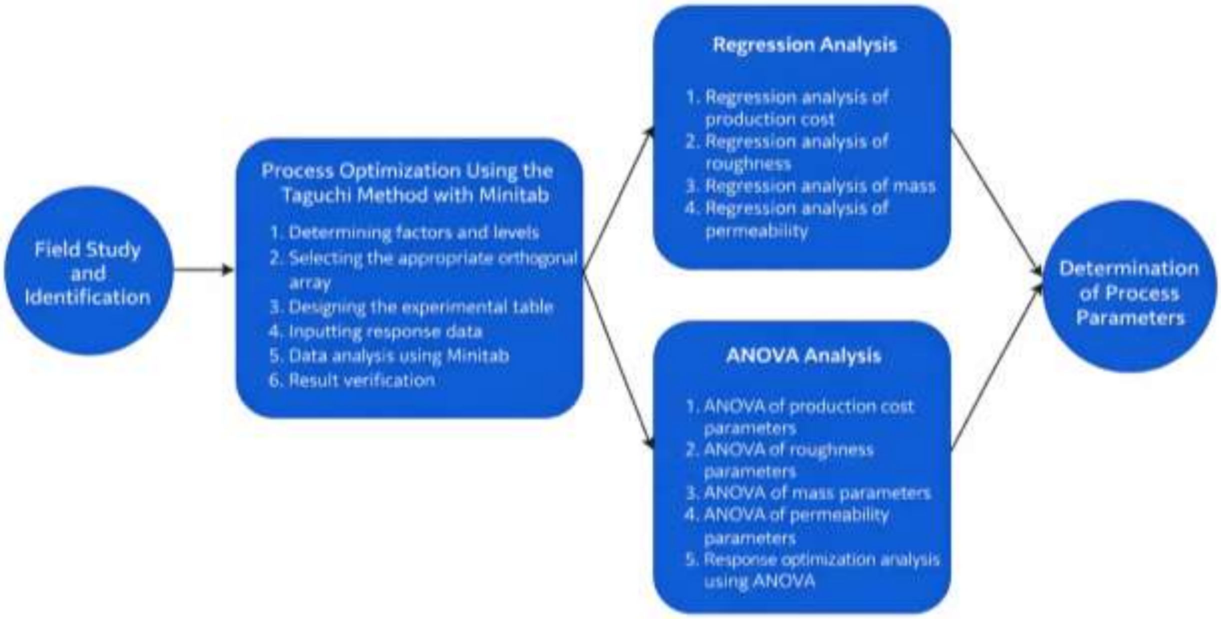

Image 3 Research Flowchart

The feasibility decision for the raw material composition was obtained in ANOVA with a standard value of 0.4 , while for the production process it was obtained in regression 0.5. The value of 0.4 in the ANOVA analysis was used because it showed that the factor was able to explain at least 40% of the response variation, so it was considered sufficiently influential and feasible to be used as a basis for decision making. Meanwhile, the value of 0.5 in the regression analysis was used because the model is considered feasible if it can explain at least 50% of the response variation, making it strong enough to be used as the basis for production process analysis.

1) Primary and Secondary Data

Primary data is data collected directly through field observations. In this study, primary data includes the ratio of material composition, combustion temperature, combustion duration, and LECA diameter. The parameters of material composition ratio, combustion temperature, combustion duration, and LECA diameter were determined based on literature studies, material characteristics, equipment limitations, and preliminary experiments. These parameters were then used as control factors and levels in the Taguchi method to obtain optimal conditions that produced the best LECA quality with minimum production costs.

Meanwhile, secondary data was used as supplementary information to support the research, such as data on the standard price of and the standard size of LECA available on the marketplace.

2) Field Study and Identification

Collecting data directly and identifying the main problem, namely the optimization of the *Lightweight Expanded Clay Aggregate* production process

3) Taguchi Method
   1) Determining factors and levels
   2) Determining the appropriate *Orthogonal Array*
   3) Create an experiment table
   4) Entering response data
   5) Analyze data using Minitab
   6) Verify results

This method utilizes experimental design and *Signal to Noise* Ratio (SN Ratio) analysis to determine the most optimal parameter combination [29].

4) Regression Analysis - ANOVA
   1) Production *Cost* Regression Analysis
   2) *Roughness* Regression Analysis
   3) Mass Regression Analysis
   4) *Permeability* Regression Analysis

$$Permeability = \frac{B1 - B2}{B2} \times 100\% \quad (1)$$

Where: B1: Wet LECA mass (soaked for± 24 hours)
B2: Dry LECA mass

5) Regression Optimization Response

It should be noted that the application of linear regression has limitations, because it assumes a linear relationship between independent variables and response variables, while the process of LECA formation and combustion has the potential to be non-linear. The regression model only applies to the range of data used in the experiment and cannot be used for predictions outside the testing level. In addition, the limited amount of data and the possibility of interactions between factors and uncontrolled variables can affect the accuracy of the modeling results, especially when there are other variables that may affect the production process in a non-linear manner [30]. The ANOVA method is generally used to determine whether the means of two or more populations have the same value, based on sample data representing each population [31].

5) Determination of Process Parameters

Determining the best process parameters using the most optimal method between the Taguchi, Regression, and ANOVA methods

IV. RESULTS AND DISCUSSION

A. Influence Analysis: Taguchi Method

1. Determination of Control Factors

Table 1. Determination of Control Factors

Factor	Name	Level Values	Column	Level
A	X1 Temperature P	200, 320, 520	1	3
B	X2 Duration	1, 2, 3	2	3
C	X3 Diameter	1, 1.5, 2	3	3

(Table 1 Determination of Control Factors) above is an illustration of the Taguchi method showing the factors and levels applied in the experimental design. There are three factors, each with three levels: the first factor X1 (Combustion Temperature) with levels of 200°C, 320°C, and 520°C; the second factor X2 (Burning Time) with levels of 1 hour, 2 hours, and 3 hours; and the third factor X3 (Diameter) with levels of 1 cm, 1.5 cm, and 2 cm. The values of 200, 320, and 520 were set to represent low, medium, and high variations that are still within the limits of the LECA manufacturing process. These values were determined based on a literature review, preliminary test results, and considerations of equipment limitations and material characteristics.

2. Determination of *Orthogonal Array*

Table 2. *Orthogonal Array*

Runs	3 ^ Columns
L9	3 ^ 3
L27	3 ^ 3

Based on these results, the appropriate *orthogonal array* table was selected, namely *the* L9 *matrix*, which was designed to regulate the desired factor values and interactions [27]. The nine experiments were conducted using *the* L9 *orthogonal array* to test the optimization of the LECA production process based on a mixture of kasgot [28]. By using *an orthogonal array,* the number of experiments can be adjusted to the research needs. Although there are many combinations in *the orthogonal array*, this study used L9 because each factor has three levels.

3. Response Determination

Table 3. Experiment Table

X1 Burning Temperature	X2 Duration	X3 Diameter	Process *Cost* (IDR)	Roughness	LECA Mass (g)	*Permeability* (%)
200	1	1.0	10,500	0.164	180	50.00
200	2	1.5	10,500	0.246	256	100.00%
200	3	2.0	10,500	0.376	468	50.00%
320	1	1.0	14,000	0.205	302	50.00
320	2	1.5	14,000	0.126	310	50.00
320	3	2.0	14,000	0.130	166	100.00%
520	1	1.0	17,500	0.381	573	30.00%
520	2	1.5	17,500	0.519	224	50.00%
520	3	2.0	17,500	0.109	322	50.0

Based on the above table (Table 3 Experimental Table), conducted 9 experiments with 3 variables, namely X1 (Combustion Temperature), X2 (Combustion Duration), and X3 (Diameter). The range of levels used for the experiments was 200–520°C for X1, 1–3 hours for X2, and 1–2 cm for X3. The parameters tested included the manufacturing process cost, *roughness,* LECA mass, total LECA volume, and permeability. The response variables refer to product technical standards and market standards; for example, the LECA combustion temperature ranges from 1100–1200°C. To calculate the manufacturing cost, the standard price of firewood raw materials was used, which is IDR 3,500 per bundle. The cost calculation results for each experiment are as follows: experiments one to three amounted to IDR 10,500, experiments four to six amounted to IDR 14,000, and experiments seven to nine amounted to IDR 17,500.

A roughness test was conducted to assess the level of roughness of the LECA produced. Measurements were taken using a *Surface Roughness* device, with each LECA grain from each experiment measured individually using a sensor attached to the surface, then the results were averaged. The measurement results for each experiment are as follows: the first experiment 0.164 µm, the second experiment 0.246 µm, the third experiment 0.376 µm, fourth experiment 0.205 µm, fifth experiment 0.126 µm, sixth experiment 0.130 µm, seventh experiment 0.381 µm, eighth experiment 0.529 µm, and ninth experiment 0.109 µm.

The next test parameter was the mass of LECA. After drying, each LECA was measured using a digital scale, and the results were as follows: the first experiment was 180 g, the second experiment was 256 g, the third experiment was 468 g, the fourth experiment was 302 g, the fifth experiment was 310 g, the sixth experiment was 166 g, the seventh experiment was 573 g, the eighth experiment was 224 g, and the ninth experiment was 322 g.

Permeability testing was conducted to determine LECA's ability to absorb water. The higher the water absorption, the better the quality of LECA produced[32]. The permeability measurement results for each experiment are: first experiment 50%, the second experiment 100%, the third experiment 50%, the fourth experiment 50%, the fifth experiment 50%, the sixth experiment 100%, the seventh experiment 30%, the eighth experiment 50%, and the ninth experiment 50%.

Table 4. *Roughness* Test, LECA Mass, Permeability

No	Roughness (µm)	LECA Mass (gr)	Permeability (%)
1	0.164	180	50
2	0.246	256	100
3	0.376	468	50
4	0.205	302	50
5	0.126	310	50
6	0.130	166	100
7	0.381	573	30
8	0.529	224	50
9	0.109	322	50

4. Taguchi Analysis for Production Process Cost

Table 5. *Signal to Noise Ratio of* Production Process *Cost*

Combustion Level	X1 Temperature	X2 Duration	X3 Diameter
1	-80.42	-82.74	-82.74
2	-82.92	-82.74	-82.74
3	-84.86	-82.74	-82.74
Delta	4.44	0.00	0.00
Rank	1	2.5	2.5

Based on Taguchi analysis, the effects of combustion temperature, combustion duration, and diameter on production *cost* were analyzed using the *signal-to-noise* (SN) ratio. For manufacturing cost, the *"small is better*" criterion was used, which means that a smaller value indicates a better result ( ). The analysis results show that temperature has the highest ranking (ranking 1), followed by burning time and diameter, which each received a ranking of 2.5.

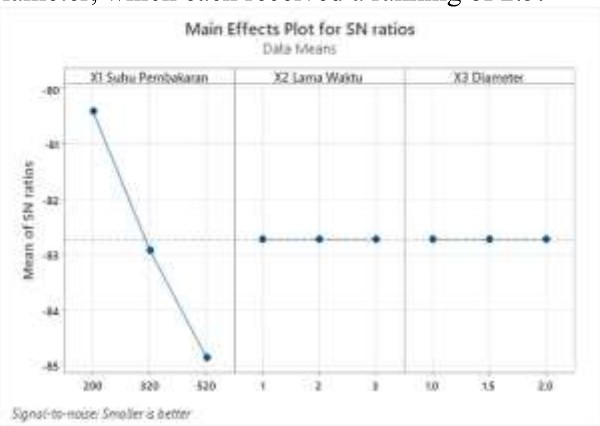

Image 4 *Signal to Noise Ratio* Graph for Production *Cost*

The Main Effects Plot for S/N Ratios graph with the "smaller is better" criterion shows that combustion temperature is the most influential factor on the research response, as indicated by significant changes in the S/N ratio value at each level. The lowest temperature produces the best S/N ratio value, while an increase in temperature tends to decrease the response performance. Meanwhile, burning time and

LECA diameter show a relatively small effect because the S/N ratio values produced tend to be constant at all levels. This indicates that controlling the burning temperature is the main factor in achieving optimal process conditions[33] .

5. Taguchi Analysis for Roughness

Table 6. *Signal-to-Noise Ratio* for *Roughness*

Combustion Level	X1 Temperature	X2 Duration	X3 Diameter
1	-12.13	-12.62	-13.04
2	-16.49	-11.96	-15.07
3	-11.11	-15.16	-11.62
Delta	5.38	3.20	3.44
Rank	1	3	2

Based on Taguchi analysis, the effects of combustion temperature, combustion duration, and diameter on the *Roughness* parameter were analyzed using the *Signal to Noise* (SN) *ratio.* For *Roughness,* the *Larger is Better* criterion was used, meaning that higher values indicate better results. The analysis results show that combustion temperature ranks first, followed by diameter in second place, and combustion duration in third place.

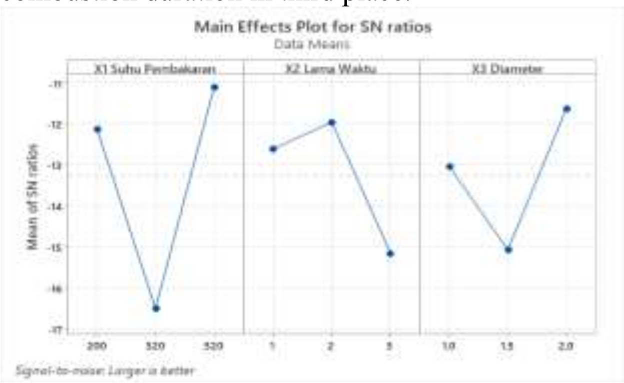

Image 5 *Signal to Noise Roughness*

Based on the Main Effects Plot for S/N Ratios graph, each process factor has a different effect on LECA quality. Combustion temperature has the most significant effect, with the highest level producing the largest S/N ratio value. Combustion duration shows optimal conditions at the medium level, while a larger LECA diameter provides a more stable response. Based on the larger is better criterion, the best parameter combination is obtained at a high combustion temperature, medium combustion time, and the largest LECA diameter. In addition, roughness also affects the movement of water and air within the media[34].

6. Taguchi Analysis for LECA Mass

Table 7. *Signal to Noise* for Leca Mass

Combustion Level	X1 Temperature	X2 Duration	X3 Diameter
1	48.89	49.96	45.50
2	47.94	48.33	49.31
3	50.78	49.32	52.80
Delta	2.83	1.62	7.29
Rank	2	3	1

Based on Taguchi analysis, the effects of combustion temperature, combustion duration, and diameter on the LECA mass parameter were analyzed using the *Signal to Noise* (SN) *ratio.* For LECA mass, the *Larger is Better* criterion was used, meaning that higher values indicate better results. The analysis results show that diameter ranks first, followed by combustion temperature in second place, and combustion duration in third place.

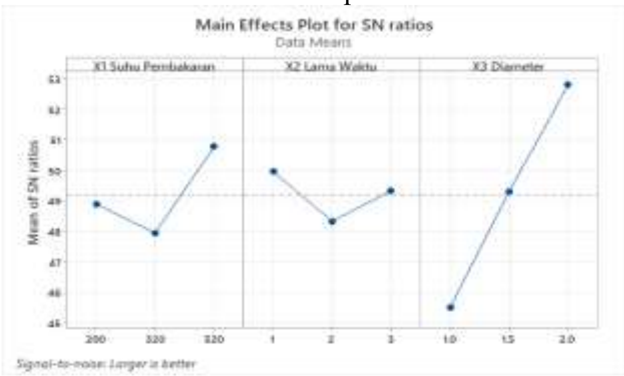

Image 6 *Signal to Noise* Graph

Based on the graph above, the line for the diameter variable appears to be the longest, indicating that diameter is the most influential factor on the LECA Mass parameter. Hydroton mass plays an important role in determining the amount of material needed to fill a certain volume in the growing medium. In addition, mass is related to the density of hydroton material, which is heavier and can provide more support for plants, but can also affect drainage and air circulation in the growing medium.

7. Taguchi Analysis for *Permeability*

Table 4 *Signal-to-Noise Permeability*

Burning Level	X1 Temperature	X2 Duration	X3 Diameter
1	-4.014	-7,500	-4.014
2	-4,014	-4,014	-4,014
3	-7,500	-4,014	-7,500
Delta	3,486	3,486	3,486
Rank	1	2.5	2.5

Based on Taguchi analysis, the effects of combustion temperature, combustion duration, and diameter on the LECA mass parameter were analyzed using the *Signal to Noise* (SN) *ratio.* For LECA mass, the *Larger is Better* criterion was applied, meaning that higher values indicate more optimal results. The analysis results show that combustion temperature ranks first, while combustion duration and diameter each rank 2.5.

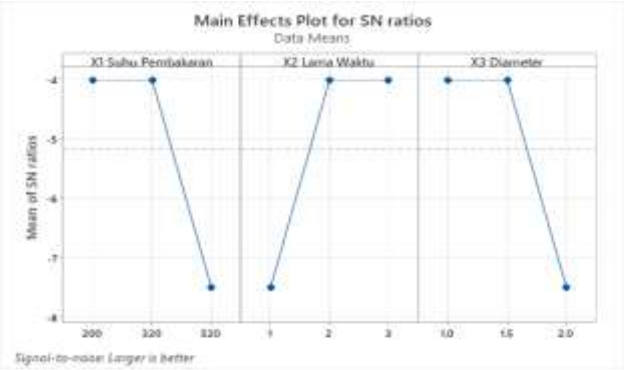

Image 7 *Signal to Noise Permeability* Graph

Based on the graph above, the line for the combustion temperature variable appears to be the longest, indicating that combustion temperature is the most influential factor on the Permeability parameter. High permeability allows water and nutrients to move smoothly through the growing medium, so that plant roots receive a consistent supply. In addition, permeability also plays an important role in maintaining good drainage and preventing waterlogging, which can cause root rot.

B. Composition Analysis: ANOVA Method

Table 9 ANOVA Parameter *Cost*

Source	DF	Adj SS	Adj-MS	F-Value	P-Value
X1 combustion temperature	2	73,500,000	36,750,000	*	*
X2 old Time	2	0	0	*	*
X3 Diameter	2	0	0	*	*
Error	2	0	0		
Total	8	73,500,000			

Anova analysis of cost parameters, the most influential factor being combustion temperature with an *Adj SS* value of 73,500,000.

Table 10. Anova Parameter *Roughness*

Source	DF	Adj SS	Adj-MS	F-Value	P-Value
X1 combustion temperature	2	0.05063	0.025314	0.62	0.618
X2 old Time	2	0.01270	0.006349	0.16	0.866
X3 Diameter	2	0.01925	0.009624	0.23	0.810
Error	2	0.08191	0.040956		
Total	8	0.16449			

Analysis of variance of *roughness* parameters, the most influential factor is combustion temperature with an *Adj SS* value of 0.05063.

Table 11. Anova Parameter Mass

Source	DF	Adj SS	Adj-MS	F-Value	P-Value
X1 combustion temperature	2	19820	9910	2.68	0.272
X2 old Time	2	11,954	5977	1.62	0.382
X3 Diameter	2	103,100	51,550	13.93	0.067
Error	2	7402	3701		
Total	8	142276			

Analysis of variance of mass parameters, the most influential factor is diameter with an *Adj SS* value of 103.100

Table 12. Anova Parameter *Permeability*

Source	DF	Adj SS	Adjusted MS	F-Value	P-Value
X1 Combustion Temperature	2	0.1089	0.05444	0.77	0.566
X2 Duration	2	0.1089	0.05444	0.77	0.566
X3 Diameter	2	0.1089	0.05444	0.77	0.566
Error	2	0.1422	0.07111		
Total	8	0.4689			

Analysis of variance of *permeability* parameters, the results of the three factors have the same *Adj SS* value of 0.1089.

Table 13 ANOVA Optimization Response Analysis

Solution	X1 Combustion Temperature	X2 Time	X3 Diameter	*Permeability* (%) Fit	LECA Mass (g) Fit	*Roughness* Fit	*Cost* of Manufacturing Process Fit
1	200	2	2	0.588889	392.556	0.352	10500

Solution	*Composite Desirability*
1	0.607448

Based on the ANOVA calculation, the optimal conditions for the LECA production process were obtained, namely a burning temperature of 200°C, a burning time of 2 hours, a, and a diameter of 2 cm. Furthermore, the optimized material was used to calculate *the standard error*. The *standard error* results obtained are 0 for cost, 0.178 for roughness, 53.7 for mass, and 0.235 for permeability, with a *composite desirability* value of 0.607448.

C. Composition Analysis: Regression Method

Production *Cost* (IDR) = 6571 + 21.43 X1 Combustion Temperature + 0 X2 Duration + 0 X3 Diameter

This calculation produces a regression equation that relates several independent variables to the manufacturing process cost (Manufacturing Process *Cost*) in rupiah (IDR) units. The equation is used to estimate or predict production costs based on certain factors. The *intercept* value (constant) of IDR 6,571 indicates that if all independent variables are zero, the base or minimum manufacturing cost is IDR 6,571. In this model, only the combustion temperature variable (X1) affects the manufacturing cost, while the combustion time (X2) and diameter (X3) have no significant effect.

Roughness = 0.156 + 0.000302 X1 Combustion Temperature – 0.0225 X2 Duration + 0.023 X3 Diameter

This calculation produces a regression equation used to predict the Roughness value based on three independent variables, namely Combustion Temperature (X1), Duration (X2), and Diameter (X3). *The intercept* (constant) value of 0.156 indicates the estimated *Roughness* value when all independent variables (X1, X2, and X3) are zero.

LECA Mass (gr) = -136 + 0.259 X1 Combustion Temperature – 16.5 X2 Duration + 260.3 X3 Diameter

This calculation produces a regression equation used to predict LECA Mass (gr) based on three independent variables, namely Combustion Temperature (X1), Duration (X2), and Diameter (X3). The *intercept* value (constant) of -136 indicates the estimated LECA Mass when all independent variables (X1, X2, and X3) are zero.

Table 14. Regression Optimization Response Analysis

Solution	X1 Combustion Temperature	X2 Duration	X3 Diameter	*Permeability (%) Fit*	LECA Mass (g) Fit	*Roughness Fit*	Processing *Cost* Fit
1	200	2.71717	2	0.669384	391.554	0.201935	10,857.1

Solution	Composite Desirability
1	0.500809

Based on regression calculations, the optimal production process conditions are obtained with a combustion temperature of 200°C, a combustion time of 3 hours, and a diameter of 2 cm. Next, the optimized material is used to calculate *the* standard *error*. The *standard error* results obtained are 388 for *cost*, 0.121 for *roughness*, 53.4 for mass, and 0.146 for permeability, with a *composite desirability* value of 0.500809.

D. Comparison Results

The results of the study show that the three methods, Taguchi, ANOVA, and Regression, have different roles in analyzing the performance of the composite kasgot LECA production process. The Taguchi method reveals that the burning temperature is the most influential variable on most quality parameters, including production costs, surface roughness, and permeability, while particle diameter is the main factor affecting LECA mass. These findings are in line with the ANOVA results, which statistically confirm that temperature and diameter contribute most significantly to response variation, as seen from the highest *adjusted sum of squares* value. Meanwhile, the regression method produced a predictive model capable of mapping the relationship between process parameters and product quality, but with a higher error rate than ANOVA. Overall, ANOVA showed the best optimization performance, marked by the highest *composite desirability* value and lowest *standard error*, especially for the cost and permeability parameters.

Table 15. Comparison of Regression Method - ANOVA Results

METHOD	X1 Burning Temperature	X2 Duration	X3 Diameter	Permeability (%) Fit	LECA Mass (g) Fit	Roughness Fit	Processing Cost Fit
Anova	200	2	2	0.588889	392.556	0.352	10500
Regression	200	2.71717	2	0.669384	391.554	0.201935	10,857.1

Method	Solution	*Composite Desirability*
Anova	1	0.607448
Regression	1	0.500809

Thus, it can be concluded that ANOVA is the most effective method in determining the optimal parameter combination, as it is capable of producing more stable, accurate, and consistent estimates compared to Taguchi and Regression.

V. CONCLUSION

A. Conclusion

Based on the Taguchi experiment results, combustion temperature is the most dominant factor affecting most quality parameters, particularly production cost, surface roughness, and permeability, while particle diameter has the most significant effect on LECA mass. These results are reinforced by ANOVA analysis, which shows that temperature and diameter contribute significantly to response variation. Through regression modeling, a prediction equation was obtained that can be used to estimate the value of each quality parameter based on process conditions. Optimization showed that the best conditions were achieved at a temperature of 200°C, a burning time of 2–3 hours, and a diameter of 2 cm, with a *composite desirability* value of more than 0.60. In addition to improving process quality and efficiency, the use of BSF maggot waste provides environmental benefits by reducing organic waste. Thus, this approach is capable of producing LECA that is more efficient, economical, and environmentally friendly. In terms of accuracy, the ANOVA method showed the lowest error rate. The *standard error* value for cost was the lowest at 0, permeability was 0.235 lower than regression, and although *roughness* was slightly higher than regression at 0.178 compared to 0.121, the total ANOVA error was still lower because the cost and permeability errors were much smaller. The ANOVA composite desirability value is also higher at 0.60 compared to regression at 0.50 ( ), proving that the ANOVA method has the lowest error rate compared to Taguchi and regression based on *standard error* calculations. With these results, it can be concluded that LECA or composite kasgot mixture innovations can be an alternative planting medium capable of absorbing water, and the kasgot mixture also functions as organic fertilizer for plants.

B. Recommendations

Considering that kasgot is organic waste, further research could include a Life Cycle Assessment (LCA) analysis to quantitatively assess its environmental impact. This would strengthen the claim that the use of kasgot as a LECA composite is more environmentally friendly.

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