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Determination of Optimal Factor Level Combination in Ceramic Making Process to Maximize Flexural Strength Using Taguchi Method (Case Study in Kasongan Ceramic UKM Center, Bantul, DIY)

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ABSTRACT

Kasongan Ceramic UKM Center is located in Kasongan Hamlet, Bangunjiwo Village, Kasihan District, Bantul Regency, DIY. Products that are cracked, curved, and easily brittle are problems currently faced by the Kasongan Ceramics UKM Center. From September 2019 to February 2020, the Kasongan Ceramics UKM Center has produced 32,256 units of ceramic products. Of the total production of 32,256 units, there were 3,873 units of defective products or 12% of the total production. The results of central ceramic products with less than optimal flexural strength are suspected to be the cause of product defects that are cracked, warped, and easily brittle. This study aims to determine the optimal factor level combination that maximizes the flexural strength using the Taguchi method in the process of making ceramics at the Kasongan Ceramic UKM Center. The steps that need to be taken to determine the optimal level factor combination that maximizes the flexural strength using the Taguchi method in the process of making ceramics at the Kasongan Ceramics UKM Center are the first to determine the controlled factors and noise factors as well as the levels that affect the flexural strength in the manufacture of ceramics at the center. After that, determine the experimental orthogonal array based on the number of factors and levels that have been determined and carry out the experiment based on the predetermined orthogonal array. The next step is to test the flexural strength in the laboratory on the experimental specimens. Data from the results of the flexural strength test will be processed to determine the optimal combination level factor that maximizes the flexural strength in the process of making ceramics at the Kasongan Ceramics UKM Center. The optimal level factor combination that maximizes the flexural strength in the process of making ceramics at the Kasongan Ceramics UKM Center using the Taguchi method is the composition of 3 parts Godean clay, 3 parts Kasongan clay composition, 1 part sand composition, and burning using an open tub.

Keywords: *Taguchi method, flexural strength, process parameters*

1. INTRODUCTION

Kasongan Ceramic UKM Center is located in Kasongan Hamlet, Bangunjiwo Village, Kasihan District, Bantul Regency, DIY. Ceramic products that are cracked, warped, and easily brittle are problems currently faced by the center. . From September 2019 to February 2020, the Kasongan Ceramics UKM Center has produced 32,256 units of ceramic products. Of the total production of 32,256 units, there were 3,873 units of defective products or 12% of the total production. The cause of ceramic products that are cracked, curved, and easily brittle is that the bending strength of the ceramic products produced by the center is not maximal.

The problems at the Kasongan Ceramic UKM Center in the form of ceramic products that are cracked, curved, and easily brittle caused by not maximizing the flexural strength of the ceramic products produced will be resolved through this research. To maximize the bending strength of ceramics in ceramic products carried out by the center, an experiment will be carried out using the Taguchi method to determine the optimal level

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combination of ceramic manufacturing factors that maximize flexural strength.

The formulation of the problem in this study is how to determine the optimal factor level combination in the manufacture of ceramics that maximizes the flexural strength in the process of making ceramics at the Kasongan Ceramics Center UKM?

The purpose of this study was to determine the optimal factor level combination in the manufacture of ceramics that maximizes flexural strength using the Taguchi method in the process of making ceramics at the Kasongan Ceramics Center UKM.

2. METHOD

2.1 Object of research

The research object is the Kasongan Ceramics UKM Center.

2.2 Types and Sources of Data

The data collected in this study consisted of two types, namely:

2.2.1 Primary data

The primary data used in this study are the raw materials used and the composition of the ceramic bodies that are generally used by the center which is obtained from interviews conducted with center management, as well as the bending strength data of ceramics obtained as a result of experiments.

2.2.2 Secondary Data

Secondary data used in this study is information about the process of making ceramics and the Taguchi method obtained from literature studies

2.3 Research Framework

The steps of this research can be seen in Figure 1.

2.3.1 Theoretical basis

a. Experimental Design

A good experimental design is a simple experimental design but produces a maximum collection of information about the object of research being researched. The experimental design is also intended to obtain maximum information about the object under study using minimum costs (Sudjana, 2002).

b. Understanding the Taguchi method

One of the off-line quality controls is to conduct an experimental design using the Taguchi method. Off-line quality control is carried out before the product is made on the production floor. According to (Febriansyah et al, 2013), off-line quality control is quality control that is carried out at the beginning of the product life cycle, namely improvement efforts made from the beginning to produce a product.

c. Experimental design according to Taguchi

To get the best design through experiments, Taguchi suggested that experimental design be carried out with the following conditions (Suhartoyo, 2015):

a) Controllable factors are separated from environmental factors (uncontrollable / noise factor) by forming two experimental designs called an inner array for design factors and an outer array for environmental factors.
b) Inner array and outer array are designed in a factor matrix. Thus, each column can be filled with factors and factor interactions that need to be evaluated.
c) The design performance is seen from the signal-to-noise ratio which shows the robustness of the design against environmental factors. The best design is indicated by the highest ratio of observations made.

d. Stages in design according to Taguchi

According to (Putri and Bayuseno, 2013), to optimize the product design or production process, there are three stages, namely:

a) System Design
Namely an effort in which new concepts, ideas, methods and others are raised to provide product improvement.
b) Design Parameters
This stage is making a physical or mathematical prototype based on the previous stage through experiments
c) Tolerance Design
Tolerance design is the determination of tolerance parameters. The tolerance parameter in question is a tolerance

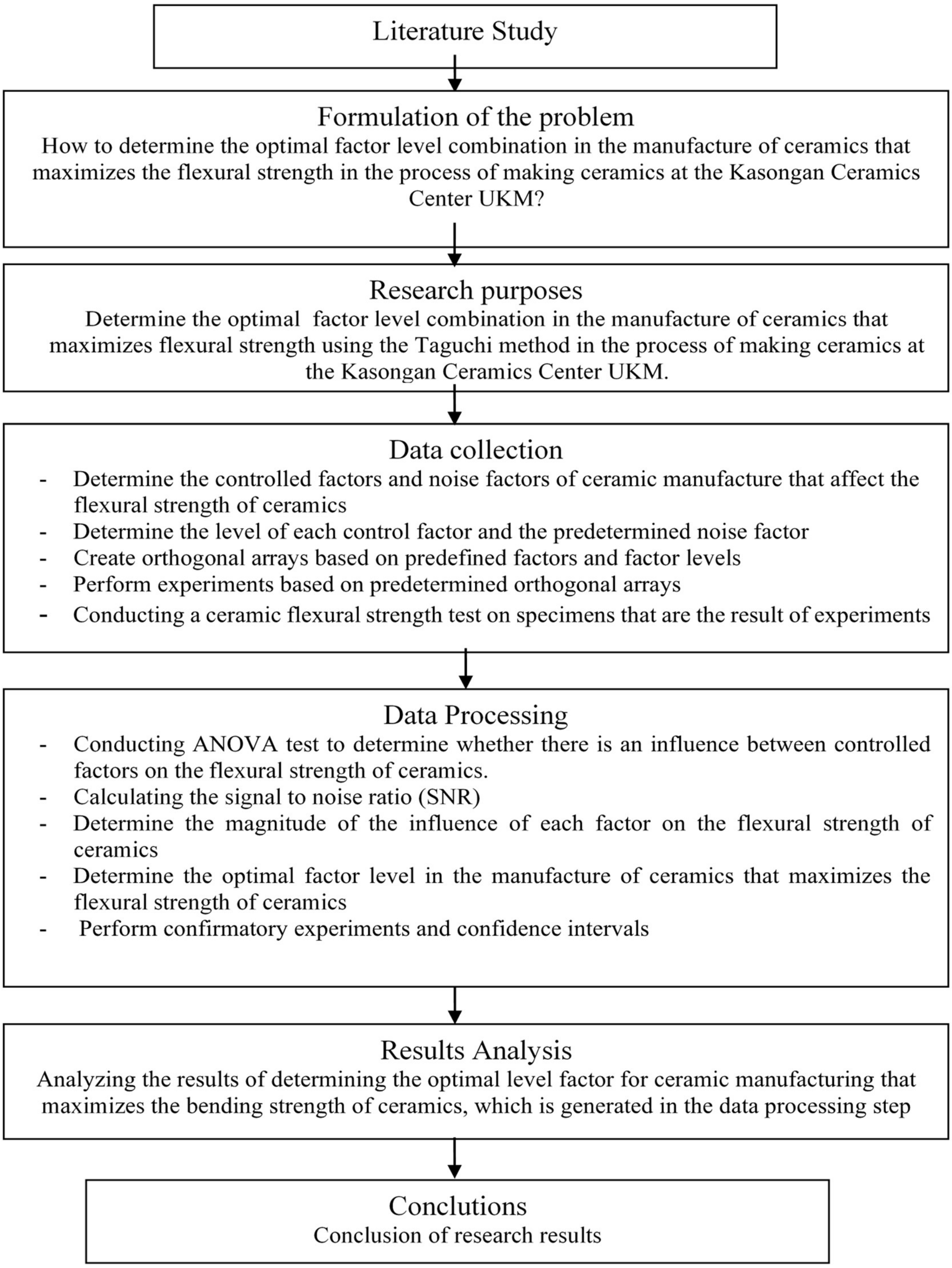

Figure 1. Research Framework

parameter related to public losses due to product deviation from the specified target.

e. State of the art

Hartono (2012) conducted a study to maximize plastic tensile strength using the Taguchi method, with the control factors studied were the composition of pure and recycled plastic ore materials, pressure, and temperature. Sidi and Wahyudi (2013) conducted a study to optimize roundness in the CNC lathe using the Taguchi method, with the control factors studied were cutting speed, infeed motion, and infeed depth. Ermawati and Hartati (2014) conducted research to improve the quality of bread using the Taguchi method, with the control factors studied were flour

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composition, butter composition, and egg composition. Sumantri and Upara (2018) conducted research to minimize surface roughness and minimize cutting time for making holes in brass material using the Taguchi method, with the control factors studied were spindle speed, depth of cut, and distance of the chisel. Halimah and Ekawati (2020) conducted a study to maximize lightweight bricks using the Taguchi method, with the control factor being the composition of water, cement, and sand. This research will maximize the flexural strength of ceramics using the Taguchi method, with the control factors studied are the composition of Godean clay, the composition of Kasongan clay, the composition of sand, and the method of burning.

f. Flexural Strength of Ceramics

The ability to withstand bending loads is a consideration that must be considered in the analysis of the strength of the ceramic body. The maximum load that can be held by the ceramic body is a measure of the quality of a ceramic product, so the strength of the ceramic that occurs is (Anggarini et al, 2017):

$$E = F_B \frac{3\,Ls}{2\,bh^2}$$

Wherever:
E: Modulus of elasticity (N / cm2).
F_B: Maximum load (N)
Ls: The distance of the specimen supports (cm)
b: Width of the specimen (cm)
h: Thickness of the specimen (cm)

g. Definition of SMEs (UKM)

Small and Medium Enterprises, abbreviated as UKM, is a term that refers to the type of small business which has a net worth of at most Rp. 200,000,000 excluding land and buildings for business premises. And a stand-alone business. According to Presidential Decree no. 99 of 1998 the definition of Small Business is: "Small scale economic activities of the people with business fields that are predominantly small business activities and need to be protected to prevent unfair business competition."

Criteria for small businesses according to Law no. 9 of 1995 are as follows:

a) Have a net worth of at most Rp. 200,000,000, - (Two Hundred Million Rupiah) excluding land and buildings for business premises
b) Have annual sales of at most Rp. 1,000,000,000, - (One Billion Rupiah)
c) Belongs to Indonesian citizens
d) Stand alone, not a subsidiary or branch of a company that is not owned, controlled, or affiliated directly or indirectly with a Medium or Large Business
e) In the form of individual businesses, business entities that are not legal entities, or business entities with legal status, including cooperatives

3. RESULTS AND DISCUSSION

3.1 Data Collection

3.1.1 Determine the control factor and the noise factor and its level

Controlled factors and noise factors and their levels that affect the flexural strength of ceramics can be seen in the Table 1 and Table

Table 1. Controllable factors

Symbol	Controllable factors	Level 1 (parts)	Level 2 (parts)
A	Composition of Godean Clay	2	3
B	Composition of Kasongan Clay	1	3
C	Composition of Sand	0,5	1
D	Burning	Open tub	Close tub

Tablel 2. Noise factors

Syimbol	Uncontrollable factors	Level 1	Level 2
E	Temperature	Cool	Hot

3.1.2 Determination of the orthogonal array

The determination of the orthogonal array is done by considering the number of controllable and noise factors as well as the level of the factors involved in the experiment. In this experiment, each controlled factor or noise factor consisted of two factor levels. The steps for determining the orthogonal array are as follows:

a) Calculation of the required degrees of freedom (df) and the total level for the controlled factor:
4 control factors, 2 levels each = A,B,C,D
= 4x (2-1)
= 4 *df* experiment
b) Determination of the appropriate Orthogonal Array for controlled factors :
Given that the experimental df is 4, the appropriate Taguchi standard orthogonal matrix is L_8 (2^7). Terms $df_{oa} \geq df_{eexperiment}$

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$L_8(2^7)$: N-1 = 8-1 = 7 df_{oa}, because 7 df_{oa} > 4 $df_{experiment}$, then the requirements are met with the orthogonal array research design used is L_8 (2^7).

Orthogonal array for noise factors. This research involves 1 noise factor with 2 factor levels, with the following calculations: df_{noise} = 1(2-1) = 1*df.* So that we get a standard design with 4 rows and 3 columns written L_4 (2^3).

3.3.3 Experimental results

The results of the experiment which are ceramic flexural strength data from each combination of factor levels in a predetermined orthogonal array can be seen in Table 3.

Table 3.The experimental results of the flexural strength test of ceramic bodies

					Outer Array							
				E		1		2	1		2	
	Inner Array											
Tri	A	B	C	D	Experimental Data (N/mm²)							
	1	2	3	4	Y_1		Y_2		Y_3		Y_4	
1	1	1	1	1	2	2	1	24,	1	1	1	1
2	1	1	2	2	1	1	1	19,	2	1	1	1
3	1	2	1	2	1	1	2	18,	2	2	2	2
4	1	2	2	1	2	2	2	17,	1	1	1	2
5	2	1	1	1	1	2	2	21,	2	1	2	1
6	2	1	2	2	2	1	2	18,	2	2	2	1
7	2	2	1	2	2	2	1	23,	2	1	1	2
8	2	2	2	1	1	2	2	28,	1	2	1	2

3.2 Data Processing

3.2.1 Anova (Analysis of Varians) calculation

The effect of each factor on the flexural strength of ceramics can be determined based on ANOVA calculations. Table 4 contains a summary of the ANOVA calculations that have been carried out.

Table 4. Results of the ANOVA calculation of flexural strength

Factors	SS	df	Mq	F calculation	F table	SS'	P %
A	82,78	1	82,78	25,49	4,00398	79,53	0,18
B	60,82	1	60,82	18,72	4,00398	57,57	0,13
C	58,02	1	58,02	17,86	4,00398	54,77	0,12
D	58,11	1	58,11	17,89	4,00398	54,86	0,12
Error	191,65	59	3,25				
Total	451,38	63					

3.2.2 Signal-to-Noise Ratio (SNR) calculation

Table 5 contains a summary of the results of the calculation of the signal-to-noise ratio (SNR) of the flexural strength of ceramics at each level factor combination.

Table 5. The results of the SNR calculation for flexural strength for each combination of factor levels

Trial No	Column A	B	C	D	SNR
1	1	1	1	1	44,50
2	1	1	2	2	43,86
3	1	2	1	2	44,70
4	1	2	2	1	44,58
5	2	1	1	1	44,69
6	2	1	2	2	45,31
7	2	2	1	2	44,72
8	2	2	2	1	44,96
	Average				**44,67**

3.2.3 Calculation of the effect of each factor

The magnitude of the influence of each factor on the bending strength of ceramics is determined based on the magnitude of the range of ceramic flexural strength values between level 1 and level 2 on each factor. The most influencing factors to the least influencing factors on the bending strength of ceramics can be seen in Table 6.

Table 6. Effect of each factor on the flexural strength of ceramics

	Controllable factors			
	A	B	C	D
Level 1	44,41	44,59	44,65	44,68
Level 2	44,92	44,74	44,68	44,65
Difference	0,51	0,15	0,03	0,03
Rank	**1**	**2**	**3**	**4**

3.2.4 Confirmation Experiment Results

The combination of optimal factor level in the process of making ceramics that maximizes the flexural strength is obtained from the calculation of the effect of each factor on the flexural strength of ceramics that has been carried out. The combination of the optimal level factor for the process of making ceramics that maximizes flexural strength is the composition of 3 parts Godean clay (A2), 3 parts Kasongan clay composition (B2), 1 part sand composition (C2), and burning in an open tub (D1). Confirmatory experiments are carried out based on the optimal combination of factor levels in the ceramic manufacturing process. The results of the confirmation experiment can be seen in table 7.

Table 7. Experimental results confirm flexural strength

	Noise factors				Average	SNR
	1	**2**	**1**	**2**		
Confirmation experiment results	21,77	21,77	21,61	21,77	21,87	44,86
	23,05	21,61	21,77	21,61		

3.2.5 Confidence interval for $\mu_{prediktion}$ and $\mu_{confirmation}$

Calculation for $\mu_{prediktion}$ using the following equation:

$$\mu_{prediktion} = \bar{y} + \left(\bar{A}1 - \bar{y}\right) + \left(\bar{B}1 - \bar{y}\right)$$

$$= \bar{A}1 + \bar{B}1 - \bar{y}$$

$$= 44,41 + 44,59 - 44,67$$

$$= 44,33$$

Then the 95% confidence interval is calculated for the prediction of the process mean ($F_{(0,05\,;\,1\,;\,29)}$ = 4,18 ; MS_e = 3,25) by using the following calculations:

$$CI = \sqrt{F_{(0,05;1;29)} x V_e x \frac{1}{n_{eff}}}$$

$$n_{eff} = 10,67$$

$$CI = \sqrt{F_{(0,05;1;29)} x V_e x \frac{1}{n_{eff}}}$$

$$CI = \pm 1,13$$

$$\hat{\mu}_{prediksi} - CI \leq \mu \leq \hat{\mu}_{prediksi} + CI$$

$$44,33 - 1,13 \leq \mu \leq 44,33 + 1,13$$

$$43,2 \leq \mu \leq 45,46$$

The confidence interval for predicting the process mean in a confirmatory experiment is the SNR confidence interval calculation ($F_{(0,05\,;\,1\,;\,29)}$ = 4,18 ; MS_e = 3,25) by using the following equation:

$$CI = \sqrt{F_{(0,05;1;29)} x V_e x \left[\frac{1}{n_{eff}} + \frac{1}{r}\right]}$$

$$n_{eff} = 10,67$$

$$CI = \sqrt{F_{(0.05;1;29)} x V_e x \left[\frac{1}{n_{eff}} + \frac{1}{r}\right]}$$

$$CI = \pm 1,72$$

$$\hat{\mu}_{konfirmasi} - CI \leq \mu \leq \hat{\mu}_{konfirmasi} + CI$$

$$44,86 - 1,72 \leq \mu \leq 44,86 + 1,72$$

$$43,14 \leq \mu \leq 46,58$$

3.3 Result Analysis

Based on the calculation of the effect of each factor in Table 6, it is known that the optimal factor level combination for the manufacture of ceramics that produces the maximum flexural strength is the composition of 3 parts Godean clay, 3 parts Kasongan clay composition, 1 part sand composition, and burning using an open tub..

From the confidence interval calculations for $\mu_{prediction}$ and $\mu_{confirmation}$ it can be seen that there is an intermediate wedge $\mu_{prediction}$ and $\mu_{confirmation}$, namely between $43,2 \leq \mu \leq 45,46$ with $43,14 \leq \mu \leq 46,58$.

4. CONCLUSION

Based on data processing and analysis that has been done, the following conclusions can be drawn: (a). The combination of the optimal level factor that produces the maximum flexural strength of ceramics in the manufacture of ceramics at UKM Kasongan Sentra Keramik is the composition of 3 parts Godean clay, 3 parts Kasongan clay composition, 1 part sand composition, and burning using an open tub. (b) The calculation of the confidence interval for $\mu_{prediction}$ and $\mu_{confirmation}$ shows a slice between $\mu_{prediction}$ and $\mu_{confirmation}$, this means that the combination of optimal factor levels produced can be applied to the industry (can be mass produced)

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