Optimal design of mechanical and physical quality of pottery using TOPSIS method

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Abstract. The quality of pottery can identify from the mechanical properties and physical properties of the pottery resistance to mold and mildew. Mechanical properties can measure by bending strength and impact strength, while physical properties can measure from water absorption. The Small Medium Enterprise (SME) production pottery in Klaten has a bending strength of 9.03 MPa, affect the strength of 0.0844 Joule/mm2 and water absorption of 14.69%. One competitive strategy is to improve product quality. Improving the quality of pottery products can be done by improving the mechanical properties and physical properties. Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is a multicriteria decision making method. TOPSIS method can provide the best alternative choice based on the quality attributes of the product used. The results from this research showed that the combination of level factors that produced the optimum quality have bending strength of 10.21 Mpa, impact strength of 0.0798 Joule/mm2, water absorption of 11.75%. Based on the sensitivity analysis of attribute weights, it found that changes in the order of priority weights were sensitive only in the order of impact strength, bending strength, and water absorption.

1. Introduction
Small Medium Enterprises (SME) with a contribution of 57.94% in Indonesia's Gross Domestic Product (GDP) in 2013 played an important role in Indonesia's economic growth [1]. The pottery industry can penetrate the domestic market and foreign markets. Increasing business competition requires businesses to be able to improve the quality of their products by the wishes of consumers. The quality of pottery can identified from mechanical properties and physical properties. Mechanical properties can measured by bending strength and impact strength and physical properties in the form of pottery resistance to mold and mildew can be measured by water absorption while the factors that are thought to influence the quality include material composition, processing time, and process temperature [2].

Currently, the company can produced pottery with an average bending strength of 9.03 MPa, impact strength of 0.0844 Joule/mm2 and water absorption of 14.69%. For the products created to be following the expected quality targets and insensitive to the interference factor (having strong performance), many experiments were carried out. Taguchi method is an experimental design to get a small number of operations [3]. The quality design introduced by Taguchi is an offline quality control method that has been widely applied in industries both in the field of mechanical engineering [4], [5], chemical engineering [6–9], textile engineering [10], Aviation engineering [11, 12], and electrical engineering [13]. The difference between this research and the research that has done lies in the object and the concept of sensitivity. This research is a development of Nurhasan's research [14] using the TOPSIS method and sensitivity analysis.
This study involved more than one response variable so that the Taguchi multi response method used. The Taguchi method used in this study is the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method, which in determining the best alternative will be strongly influenced by the quality attributes of the product used. To accommodate the dynamic weighting of product quality attributes where each individual has a different perception, this study analyses the effect of weighting attributes of bending strength, impact strength and water absorption on the quality of pottery products. The order of priority for product quality attributes by combining all possible priority sequences, which are subjective. Determination of the optimal conditions of the three response variables in this study is not only based on experimental results but also based on predictions of the value of the response variable of all combinations of factor levels formed.

2. Literature

2.1. Design experiment

Based on the activities carried out quality control can be divided into two parts, namely quality control off line and on line [15]. Offline quality control relates to activities during product development and process design. Design Experiment is offline quality control; this is experimental design with each step defined in such a way that information related to or needed for the problem being studied can be collected [16]. There are two kinds of experimental designs namely conventional experimental designs and Taguchi experimental designs. Taguchi designed an experiment with the aim of getting the factors that influence the response and its interaction with the minimum number of experiments and selecting the best factor level with certain criteria as optimal parameters. Taguchi’s strategy for minimizing the number of experiments is shown by examples of experiments with 7 factors, the following 2 levels [17]:

![Figure 1. Full-Factorial Experiment.](image1)

![Figure 2. 1/16 Fractional-Factorial Experiment.](image2)

Base on figure 1. In the full factorial, experiment needed 27=128 factor level combination; the process of minimizing the number of experiments shown in figure 2, which only requires eight factor level combinations.

2.2. Sensitivity analysis

Sensitivity analysis intended to determine the effect of changes in production parameters on the performance of the production system [15]. In the TOPSIS method, in determining the chosen alternative, it will be influenced by the level of importance or the weight of the quality attributes of each response variable. The weight value of product quality attributes is dynamic and subjective, or in other words, each can have different perceptions or perceptions that change over time. To accommodate the dynamic and subjective value of product quality attributes, a sensitivity analysis was conducted to determine the effect of priority attributes of product attributes on quality.

3. Method

The study using the Taguchi experimental design model was intended to determine the factors that significantly influence the quality of pottery products based on mechanical properties as measured by bending strength and impact strength, physical properties measured by water absorption and determine...
the combination of factor levels that will produce products with the best quality. Because in this study involving more than one response variable, the Taguchi multi response method used. The Taguchi method used in this study is the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method, to accommodate the dynamic weighting of product quality attributes or in other words each can have different perceptions or perceptions that change over time then in this study an analysis of the effect of weighting attributes of bending strength, impact strength and water absorption on the quality of pottery products was carried out. The research was conducted at an SME that produced pottery, and sample testing was carried out in the laboratory.

4. Result and Discussion

4.1. Experiment planning

Regarding the information needs used in conducting experiments, in this study, the experiment planning steps were carried out as follows [14]:

1. Selection of product quality characteristics

In this study we take 3 response variables as a measure of quality, namely Bending Strength (MPa) unit with characteristics of LTB (larger the better), and Impact Strength of Joule /mm2 units with characteristics of LTB (larger the better) representing the parameters of pottery products strong, as well as a percentage unit Water Absorption (%) with the characteristics of STB (smaller the better) as a parameter of pottery products that are resistant to mold.

2. Identification and selection of factors that are thought to influence the quality of pottery products produced along with the level of factors. The factors that are thought to influence the quality in this experiment are divided into 2 factors, namely the control factor and the noise factor shown in the following table:

| No | Controlled factor       | Code | Level 1 | Level 2 |
|----|------------------------|------|---------|---------|
| 1  | Drying time            | A    | 5 Days  | 7 Days  |
| 2  | Plastic Soil Composition| B    | 4 Box   | 6 Box   |
| 3  | Less plastic soil composition| C    | 4 Box   | 6 Box   |
| 4  | Fine sand composition  | D    | 0.7 Box | 1 Box   |
| 5  | Abu Strawberry composition| E    | 0 Box   | 0.5 Box |
| 6  | Holding Time           | F    | 0 minute| 30 minutes|
| 7  | Sintering              | G    | 8000 C  | 9000 C  |
| 8  | Size of screen         | H    | 80 mesh | 120 mesh|

4.2. Experimental implementation

To identify Bending Strength, the Impact Strength and Water Absorption experiments were carried out using the internal array L8 27 and the L4 outer array 23. The experimental data shown in the following table:

| Controlled Factor | Noise Factor (H) |
|-------------------|------------------|
| A  | B  | C  | D  | E  | F  | G  | Result of Bending | Result of impact | Result of Water |
| 1  | 1  | 1  | 1  | 1  | 1  | 1  | 13.00  | 10.49  | 6.38  | 3.30  | 0.07  | 0.09  | 0.14  | 0.09  | 13.99 | 14.50 | 14.08 | 14.52 |
| 2  | 1  | 1  | 1  | 2  | 2  | 2  | 11.99  | 9.79   | 14.27 | 4.56  | 0.07  | 0.08  | 0.15  | 0.06  | 11.29 | 12.94 | 12.23 | 12.37 |
| 3  | 1  | 2  | 2  | 1  | 2  | 2  | 11.36  | 10.91  | 10.36 | 8.22  | 0.04  | 0.03  | 0.09  | 0.16  | 11.94 | 12.22 | 11.10 | 11.75 |
| 4  | 1  | 1  | 2  | 2  | 1  | 1  | 5.84   | 6.46   | 10.23 | 7.22  | 0.08  | 0.18  | 0.07  | 0.13  | 14.14 | 15.32 | 13.95 | 15.14 |
| 5  | 1  | 2  | 1  | 1  | 2  | 2  | 10.22  | 8.03   | 8.53  | 12.03 | 0.04  | 0.07  | 0.18  | 0.08  | 15.19 | 13.60 | 14.86 | 14.75 |
| 6  | 2  | 1  | 2  | 1  | 2  | 2  | 9.53   | 8.41   | 10.36 | 7.91  | 0.09  | 0.07  | 0.05  | 0.11  | 14.58 | 15.33 | 13.36 | 14.47 |
| 7  | 2  | 2  | 1  | 1  | 2  | 1  | 12.15  | 4.17   | 8.98  | 13.07 | 0.06  | 0.08  | 0.11  | 0.07  | 12.05 | 15.91 | 14.65 | 14.78 |
| 8  | 2  | 2  | 1  | 2  | 1  | 2  | 4.72   | 9.08   | 2.09  | 5.75  | 0.18  | 0.12  | 0.19  | 0.15  | 13.73 | 12.87 | 13.10 | 12.08 |
5. Data Processing
Based on experimental data, to determine the combination of level factors that produce the optimum quality of pottery, the following steps:

5.1. Signal to noise ratio (SNR) and the effect of each factor
Determine S/N Ratio for variable response Bending Strength and Impact Strength based on the objective function LTB, while S/N Ratio for variable response Water Absorption based on the objective function STB. Based on table 4-6 value of SNR showed on the table 7:

| Controlled factor | SNR | Bending Strength | Impact Strength | Water Absorption |
|-------------------|-----|------------------|-----------------|------------------|
|                   |     |                  |                 |                  |
| 1                 | 1   | 1                | 1               | 1                |
| 2                 | 1   | 1                | 1               | 2                |
| 3                 | 1   | 2                | 1               | 2               |
| 4                 | 1   | 2                | 2               | 1               |
| 5                 | 2   | 1                | 2               | 1               |
| 6                 | 2   | 1                | 2               | 1               |
| 7                 | 2   | 1                | 2               | 1               |
| 8                 | 2   | 2                | 1               | 1               |

5.2. Effect of each factor
The effect of each factor intended to find out the formulation, which will produce the best combination of level factors for each response variable. Based on table 7, the effect of each of the following control factors can be determined:

- The best combination of level factors bending strength: A1, B1, C2, D1, E1, F2, G1.
- The best combination of level factors Impact Strength: A1, B1, C1, D2, E1, F1, G1.
- The best Combination of level factors Water Absorption: A1, B1, C1, D1, E1, F2, G2.

Because the optimal factor level combination in each response variable is different, therefore, a multi-response analysis needed, the factors that influence the quality simultaneously are A, C, D, F and G so that an analysis of 25 alternative combinations and slices is needed with L8, AO, 27, obtained 38 alternatives as follows table:

Table 4. 38 Alternative of level factor combination in experiment.
5.3. Determination of optimal factor levels using TOPSIS

We found optimal condition from the different level factor, the analysis needed to optimize the different conditions using Taguchi multi-response used in this study is the TOPSIS procedure.

- The combination of the level factors used by the company is A1, B1, C2, D1, E1, F1, and G1. The combination of the level of optimal bending strength factors is A1, B1, C2, D1, E2, F2, and G2. This is able to increase the average bending strength value from 9.03 MPa to 12.33 MPa or up 3.30 MPa, so that k = 2187.5 / 3.302 = 200.8724
- The combination of the level of optimal factor impact strength is A2, B2, C1, D2, E1, F1, and G1. This is able to increase the average impact strength value from 0.0844 J/mm² to 0.1485 J/mm² or up 0.0641 J/mm², so k = 14.589 / 0.06412 = 3550.6630
- The combination of optimal water absorption factor levels is A1, B2, C1, D2, E1, F2, and G2. This is able to reduce the average water absorption value from 14.69% to 11.15% or down 3.53%, so k = 2014.589 / 3.53 2 = 161.6728, the following TOPSIS value is obtained:

| Trial | TOPSIS | Trial | TOPSIS | Trial | TOPSIS | Trial | TOPSIS |
|-------|---------|-------|---------|-------|---------|-------|---------|
| 1     | 0.46578 | 11    | 0.22029 | 21    | 0.61803 | 31    | 0.38616 |
| 2     | 0.50848 | 12    | 0.75122 | 22    | 0.65831 | 32    | 0.43041 |
| 3     | 0.36644 | 13    | 0.67859 | 23    | 0.52053 | 33    | 0.90956 |
| 4     | 0.40903 | 14    | 0.72026 | 24    | 0.56073 | 34    | 0.99957 |
| 5     | 0.80543 | 15    | 0.58684 | 25    | 0.10511 | 35    | 0.37721 |
| 6     | 0.84305 | 16    | 0.62844 | 26    | 0.15453 | 36    | 0.42414 |
| 7     | 0.71367 | 17    | 0.25877 | 27    | 0      | 37    | 0.43241 |
| 8     | 0.75122 | 18    | 0.30414 | 28    | 0.56073 | 38    | 0.75822 |
| 9     | 0.31966 | 19    | 0.15365 | 29    | 0.48365 |       |         |
| 10    | 0.36641 | 20    | 0.19894 | 30    | 0.52798 |       |         |

5.4. Sensitivities analysis

The combination of level factors that produce the optimal response obtained by attribute weights with the priority order of bending strength, water absorption and impact strength. Based on changes in the order of priority attribute weights, the changes in priority weight order are not sensitive to the optimal factor level combination, except in the priority sequence with the order of impact strength, bending strength and water absorption. The optimal combination of factor levels in this condition shown in table 8 with number of experiment 34 i.e: A1, B1, C1, D2, E2, F2, and G2. This combination of level factors results in bending strength of 10.15 MPa, rising by (10.15 MPa - 9.03 MPa = 1.12 MPa or increase 12.04%), impact strength of 0.0880 Joule/mm2 increases by (0.0880 Joule/mm2 - 0.0844 Joule/mm2 = 0.0036 or up 4.27%), water absorption of 12.21% or down (14.69% - 12.21% = 2.48% or decrease 16.89% to the original value, which means that all response variables will improve in quality.

6. Conclusion and Recommendation

Based on data analyst conclusion this research is: a). Optimum quality of pottery is produced from combination of factor levels A1, B2, C2, D1, E1, F2, and G2 i.e. the production process run with a drying time of 5 days, composition soil plastic are 6 containers, composition of soil less plastic are 6 containers, composition of fine sand are 0.7 containers, composition of straw ash zero containers, holding time 30 minutes and sintering temperature are 9000 C This conditions produces bending strength of 10.21 MPa, increased by 13.07%, impact strength of 0.0798 Joule/mm2, decreased by or 5.45%, water absorption of 11.75 %, decrease 20.01 % from the initial value. This condition shows that there is a high quality increase in bending strength and water absorption aspects, but there is a decrease in the quality of the impact strength aspect. b) Based on the sensitivity analysis shows that the change in priority weight sequence is not sensitive to the optimal factor level combination, except in the priority sequence with the order of impact strength, bending strength and water absorption.

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7. References

[1] -, “UMKM Menyumbang 57,94% Terhadap PDB Nasional,” 02 03 2014. [Online]. Available: http://www.beritamoneter.com/umkm-menyumbang-5794-terhadap-pdb-nasional/.

[2] T. S. &. S. Saito, Pengetahuan Bahan. Pradnya Paramita, Jakarta: Pradnya Paramita, 2005.

[3] N. Belavendram, Quality by Design: Taguchi Techniques for Industrial Experimentation, New Jersey: Prentice Hall International, , 1995.

[4] K. P. R. R. B. A. G. M. P. R. Konda, International Journal of Quality & Reliability Management, vol. 16, no. -, pp. 56-71, 1998.

[5] K. N. A. S. B. P.B.S. Reddy, International Journal of Quality & Reability Management, vol. 15, no. -, pp. 645-668, 1998.

[6] E. S. R. Urmila M. Diwekar, Industrial and Engineering Chemical Research, vol. 33, no. -, p. 292–298, 1994.

[7] T. S. A. Tong, International Journal of Industrial Engineering, vol. 3, no. -, p. 183–193, 1996.

[8] M. Hartono, Jurnal Teknik Industri Politeknik Negeri Malang , Vols. 13, no 1, pp. 93-100, 2012.

[9] N. H. A. Y. A. Setiawan, Dinamika Teknik , Vols. vi, no 2, pp. 27-34, 2012.

[10] M. F. L. Zulfah, Jurnal Teknik Industri Universitas Pancasakti Tegal, Vols. 3, No 3, pp. 13-18, 2013.

[11] D. B. M.A. O'Hara, IEEE Transactions on Magnetics, vol. 31, p. 2955–2957, 1995.

[12] S. O. E. J. A. F. M. Uwe Lautenschlager, Journal of Guidance, Control, and Dynamics, vol. 1126–1132, p. 18, 1996.

[13] R. A. B. H. P. Wynn, Quality and Reliability Engineering International, vol. 12, p. 119–127, 2018.

[14] M. N. A., 07 06 2018. [Online]. Available: https://dspace.uii.ac.id/handle/123456789/7947. [Accessed 21 01 2019].

[15] I. Soejanto, Desain Eksperimen Dengan Metode Taguchi, Yogyakarta: Graha Ilmu, 2009.

[16] Sudjana, Desain dan Analisis Eksperimen, Bandung: Tarsito, 1991.

[17] P. J. Ros, Taguchi Technique For Quality Engineering, New York: Mc,Graw-Hill,Inc, 1988.