

ANALYSIS OF OPTIMUM BRAIDING PROCESS PARAMETERS ON A TUBULAR BRAIDING MACHINE USING DESIGN OF EXPERIMENT

Risky Ayu Febriani¹, Ilham Ali Arridho², Rani Nopriyani³, Syahril Badaruddin⁴

^{1,2,3,4,5} Politeknik Manufaktur Bandung

Correspondence: syahrilbadaruddin@gmail.com

Article Info**Article history:**

Received Feb 18th, 2026

Revised Apr 20th, 2026

Accepted May 26th, 2026

Keyword:

Braiding, Desain Of experiment, Tensile Strength, Rope, Taguchi, Parameters

ABSTRACT=

Bandung Regency is one of the centers of home based industries producing various types of ropes such as macrame ropes, shoelaces, and prusik ropes. The manufacturing process generally employs conventional braiding machines with a trial-and-error approach. This condition leads to inconsistent product quality, particularly in terms of tensile strength, which does not always meet the required standards. The objective of this study was to identify the key parameters of the braiding process, analyze their effects on product quality, and determine the optimum combination of parameters to improve rope tensile strength. The methodology employed was the Design of Experiment (DoE) with the Taguchi approach. The investigated parameters included core count, take-up rate, and yarn count. The analysis of S/N ratio and ANOVA revealed that all three parameters contributed to tensile strength, with the most significant effect attributed to core count (35.70%), followed by yarn count (28.94%) and take-up rate (22.18%). The optimum parameter combination was determined as (core count: 9, take-up rate: High, and yarn count: 8). The confirmation test under this setting resulted in a tensile strength of 2.219 kN (226.29 kg). Although the effects were not statistically significant (F-table > F-value), the practical trend indicated strong relevance in improving rope production quality.



© 2026 Risky Ayu Febriani, Ilham Ali Arridho, Rani Nopriyani, Syahril Badaruddin Published by Permata Harmoni Abadi. This is an open access article under the CC BY license (<https://creativecommons.org/licenses/by/4.0/>)

INTRODUCTION

Bandung Regency is one of the home industry centers producing various types of ropes such as macrame ropes, shoelaces, and prusik ropes, which are widely used for household purposes, fashion, and outdoor activities. These home-based industries play an important role in meeting market demand; however, many producers have limited technical understanding of the effects of process parameters on rope quality, particularly tensile strength, which is the most critical mechanical property for assessing product performance.

Rope manufacturing is carried out through a braiding process using braiding machines, with the May-pole type being among the most commonly used. Braiding is a technique of intertwining three or more yarns diagonally to form a regular structure (Kyosev, 2014). The fibers used as raw materials for rope manufacturing are generally categorized into two types: natural fibers and synthetic fibers. Synthetic ropes are usually made from plastic-based materials such as nylon, polypropylene, and polyester. Compared to natural fiber ropes, synthetic ropes offer several advantages, including higher strength, better resistance to decay, and longer service life (Wuriyudani et al., 2017).

The quality of ropes is not solely determined by the material but also by the braiding process parameters such as take-up rate, yarn count, and core count. These three factors influence braiding angle, density, stress distribution, and mechanical properties such as tensile strength, flexibility, and durability. A high take-up rate generally produces a looser structure; a higher yarn count increases strength but reduces flexibility (Omeroglu, 2006; Hamouda et al., 2020); while an increase in core count affects load distribution and deformation capacity (Zemtsov et al., 2015). Previous studies (Omeroglu, 2006; Hamouda et al., 2020) have also confirmed that optimizing braiding parameters can enhance tensile strength and elastic modulus while reducing strain, indicating that structural density is a key factor in rope tensile resistance.

Despite its great potential, most home industries in Bandung Regency still rely on trial-and-error methods to determine production parameters, resulting in inconsistent product quality that often

fails to meet standards. Furthermore, studies on the influence of braiding process parameters in home industries remain limited.

To address this issue, the present study employs the Design of Experiment (DoE) method with a Taguchi approach. This method was chosen for its ability to improve experimental efficiency with a minimal number of trials while maintaining result validity (Soejanto, 2009). According to Seongjin (2017) in the International Journal of Automotive Technology, the Taguchi method has proven effective for optimizing process parameters using orthogonal arrays, thereby identifying the most significant factors while reducing product quality variation. Based on this foundation, the aim of this study is to determine the optimal combination of braiding parameters so that the resulting ropes achieve higher quality, consistency, and compliance with market standards.

RESEARCH METHODS

This study employed a quantitative method with an experimental approach. Figure 1 illustrates the stages of the research, which were carried out in three steps as follows :

- (1) Research Design : The initial stage of the study began with a literature review to identify the factors influencing the quality of the braiding process. Subsequently, the rope material used as the research object was determined. Following this, the Design of Experiment was structured using the Orthogonal Array approach to arrange the experimental combinations efficiently.
- (2) Experiment Implementation : At this stage, rope specimens were produced according to the DOE design. The resulting specimens were then tested to evaluate their quality. The test data were subsequently analyzed for distribution using a normality test to determine the appropriate statistical analysis method.
- (3) Data Analysis : The validated data were analyzed using the Taguchi method and ANOVA to evaluate the influence of each factor. The results were verified through a confirmation test, allowing the determination of the optimum parameter combination and its contribution to the rope braiding process.

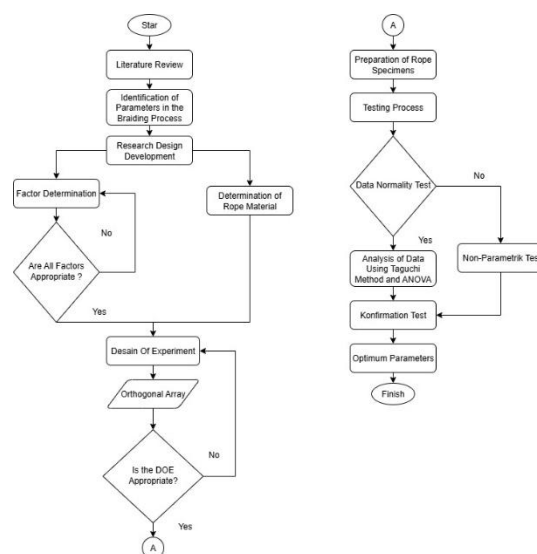


Figure 1. Systematic prosedur

The yarn material used in this study was polyester filament. The selection of polyester filament was based on several considerations, namely its lower cost, resistance to chemicals, dimensional stability, and availability in the market. Compared to polyamide (nylon), polyester is more suitable for production needs at the Micro, Small, and Medium Enterprises (MSME) scale, primarily due to cost factors, which play the most important role in determining production efficiency.

2.1. Taguchi Metode

Dr. Genichi Taguchi was the first to introduce this method, which represented a new methodology in the field of engineering. The primary objective of this method is to improve product quality beginning from the production process, thereby minimizing costs and resource utilization. The focus of this method is

on enhancing product quality by identifying the factors that influence it and classifying them into controllable factors and uncontrollable (noise) factors (Soejanto, 2009).

In its application, the factors affecting quality are divided into levels. Subsequently, an orthogonal array (OA) is selected as an experimental tool, which enables the execution of experiments with a minimal number of trials while still yielding optimal information. The experimental results are analyzed using the Signal-to-Noise Ratio (S/N Ratio) and Analysis of Variance (ANOVA) to determine the most influential factors and levels on product quality (Soejanto, 2009).

2.1.1. Orthogonal Array

An orthogonal array (OA) is an experimental matrix in the form of rows and columns, where each column represents a factor under investigation, while each row indicates a combination of factor levels. It is termed "orthogonal" because the distribution of levels in each factor is balanced and can be analyzed independently of other factors (I. Soejanto, 2009). According to the Taguchi method, the number of rows in an OA corresponds to the number of experiments that must be conducted with different level combinations. The selection of the OA type is determined based on the degree of freedom (DOF), which represents the minimum number of experiments calculated from the number of factors and levels. The OA notation is expressed as follows:

$$L_n (I^q) \quad (1)$$

Table 1. Orthogonal Array

2 Level	3 Level	4 Level	5 level	Mixed-level series
$L_4(2^3)$	$L_9(3^4)$	$L_{16}(4^5)$	$L_5(2^6)$	$L_{18}(2^1, 3^7)$
$L_8(2^7)$	$L_{27}(3^{13})$	$L_{64}(4^{21})$		$L_{36}(2^1, 3^{12})$
$L_{12}(2^{11})$	$L_{81}(3^{40})$			
$L_{16}(2^{13})$				
$L_{32}(2^{31})$				

The selection of an orthogonal array is based on the standard table, as presented in Table 1. After determining the appropriate orthogonal array, the next step is to calculate the degree of freedom (DOF). The DOF represents the number of experiments that must be conducted and serves as a reference for selecting the orthogonal array. The DOF of the experiment must be equal to or greater than the standard degree of freedom.

2.1.2. Signal Noise To Ratio

One of the important approaches in the Taguchi method is the Signal-to-Noise Ratio (S/N Ratio), which is used to analyze data distribution characteristics and to evaluate the effect of each factor in an experiment. The S/N Ratio is obtained from the transformation of repeated experimental data, thereby representing both the quality and the stability of the observed variations. A higher S/N Ratio indicates better response quality, as it reflects the lower influence of disturbance (noise) factors on the results. According to Taguchi, there are three main categories of quality characteristics in S/N Ratio analysis, namely:

$$S/N = -10 \log \times MSD \quad (2)$$

1. Smaller is Better

S/N Ratio this characteristic type is employed for optimization of responses where the criterion follows the "smaller is better" principle

$$MSD = \frac{\sum_{i=1}^n y_1^2 + y_2^2 + y_3^2 + \dots + y_n^2}{n} \quad (3)$$

2. Larger is Better

S/N Ratio this characteristic type is employed for the optimization of responses where the criterion follows the "larger is better" principle

$$MSD = \frac{\sum_{i=1}^n 1/y_1^2 + 1/y_2^2 + 1/y_3^2 + \dots + 1/y_n^2}{n} \quad (4)$$

3. Normal is Best

S/N Ratio this characteristic type is employed for optimization of responses where the criterion follows the "nominal is best" principle

$$MSD = \sum_{i=1}^n \frac{(y_1 - y_0)^2 + (y_2 - y_0)^2 + (y_3 - y_0)^2 + \dots + (y_n - y_0)^2}{n} \quad (5)$$

In this study, the larger is better characteristic was employed, since a higher rope strength indicates better product quality

2.2. Desain Of Experiment

The first step in designing the experiment was to identify the quality characteristic and select the braiding process parameters

In the braiding process, the most controllable parameters are the core count, the take-up rate, and the yarn count. Other parameters, such as braid pattern and yarn tension, could also be controlled in principle; however, these cannot be adjusted on conventional braiding machines and were therefore not selected as controlled parameters.

The quality characteristic selected in this study was the tensile strength of the rope, as tensile strength is the most crucial mechanical property in evaluating product performance.

After the process parameters and quality characteristics were defined, the next step was to determine the number of levels for each parameter.

The parameter ranges were established based on preliminary trials, brainstorming, and recommendations from local SMEs, namely core count at (4, 7, 9), take-up rate at (low, medium, high), and yarn count at (6, 7, 8). In this study, three levels of the braiding parameters were selected, as presented in Table 2.

Table 2. Level Parameters

Factors	Level		
	1	2	3
Core Count	4	7	9
Take Up Rate	Low	Medium	High
Yarn Count	6	7	8

After determining the experimental factors and levels, the next step was to select an appropriate orthogonal array. The selection of the orthogonal array was based on the number of levels and the degrees of freedom (DOF), which were calculated using the following equation.

$$DOF = \text{number of factors} \times (\text{number of level} - 1) \quad (6)$$

$$DOF = 3 \times (3 - 1) = 6$$

In this study, three factors with three levels were considered, resulting in six degrees of freedom. According to the Taguchi standard table, the appropriate orthogonal array is $L_9(3^4)$. Accordingly, a total of nine experimental trials were conducted, as presented in Table 3.

Table 3. Experimental

No	Core Count	Take Up Rate	Yarn Count
1	4	Low	6
2	4	Medium	7
3	4	High	8
4	7	Low	7
5	7	Medium	8
6	7	High	6
7	9	Low	8
8	9	Medium	6
9	9	High	7

2.3. Experimental Detail And Result

This study was carried out using a conventional braiding machine as the primary equipment for rope fabrication. Polyester filament yarns were first combined using a dubbing device and then wound onto bobbins, which were mounted on the machine carriers to ensure yarn stability and control. The braiding process was performed on a

maypole braiding machine to produce a tubular braided structure, with the carriers moving according to a predetermined pattern.

The experimental testing was conducted through tensile tests using a WAW-2000E Computerized Electro-hydraulic Servo Universal Testing Machine, as shown in Figure 2. This machine is capable of performing tensile, compression, and bending tests.



Figure 1. Tensile Strength Test

Table 4. Rope spesiment

Experiment	1	2	3
Visualizati on			
Experiment	4	4	6
Visualizati on			
Experiment	7	8	9
Visualizati on			

Table 4 presents the specimens produced from the braiding process for each experimental trial, which were subsequently subjected to tensile testing. After the braided

ropes were fabricated, their diameters were measured using a vernier caliper to ensure that they met the required tolerance of ± 0.5 mm. Following the measurement, tensile tests were conducted using a Universal Tensile Strength Machine to obtain the maximum tensile strength of each specimen. The tensile strength data obtained from the tests were then analyzed with respect to the parameters of core count, take-up rate, and yarn count in order to determine the optimum parameter combination as well as to evaluate their influence and percentage contribution to the tensile strength.

3. RESULT AND DISCUSSION

In this study, a Design of Experiment (DOE) was employed using the Taguchi method. The experimental parameters included core count, take-up rate, and yarn count. Tensile tests were conducted on the braided rope

specimens, and each trial was replicated three times. The results of the tensile strength tests are summarized in Table 5.

Table 5. Experimental Result

EXP	Variabel			Tensile Test Data (kN)		
	Core Count	Take Up Rate	Yarn Count	Replikasi		
				1	2	3
1	4	Low	6	0.874	0.870	0.896
2	4	Medium	7	0.625	1.042	0.752
3	4	High	8	1.574	1.654	1.590
4	7	Low	7	1.145	1.327	1.200
5	7	Medium	8	1.301	1.396	1.316
6	7	High	6	1.084	1.280	0.880
7	9	Low	8	1.450	1.570	1.485
8	9	Medium	6	1.643	1.331	0.992
9	9	High	7	2.054	1.581	1.544

3.1. Signal to Noise Ratio Analysis

Signal-to-Noise (S/N) ratio is one of the methods used to analyze the distribution characteristics of the data and to evaluate the influence of each factor in an experiment. The S/N ratio values are obtained through the transformation of several repeated data sets, so that the values represent the quality of the observed variations. The mean, MSD, and S/N ratio results are presented in Table 6.

Table 6. Results of Data Processing

Exp	Variabel			Tensile Test Data (kN)					
	Core Count	Take Up Rate	Yarn Count	Replikasi			$\bar{Y}$	MSD	S/N Ratio
				1	2	3			
1	4	Low	6	0.874	0.870	0.896	0.880	1.29196	-1.132
2	4	Medium	7	0.625	1.042	0.752	0.806	1.74978	-2.429
3	4	High	8	1.574	1.654	1.590	1.606	0.38824	4.108
4	7	Low	7	1.145	1.327	1.200	1.224	0.67502	1.706
5	7	Medium	8	1.301	1.396	1.316	1.338	0.56045	2.514
6	7	High	6	1.084	1.280	0.880	1.081	0.91756	0.374
7	9	Low	8	1.450	1.570	1.485	1.501	0.44492	3.517
8	9	Medium	6	1.643	1.331	0.992	1.322	0.65037	1.868
9	9	High	7	2.054	1.581	1.544	1.726	0.35219	4.868

Analysis of the Signal-to-Noise (S/N) ratio was conducted to determine the factor with the most significant effect on the tensile strength response of the braided ropes. The “larger-is-better” characteristic was employed in order to maximize the tensile strength. The average S/N ratio values for each factor level are presented in Table 2, while the influence of each factor is illustrated in the Main Effect Plot shown in Figure 3.

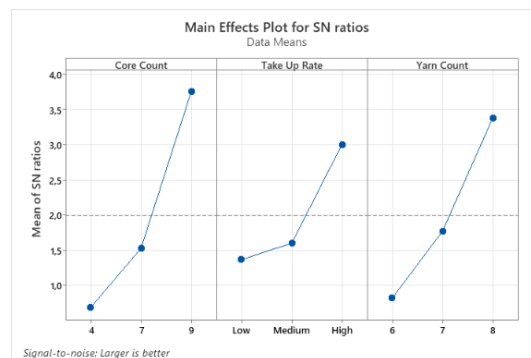


Figure 2. Grafik Main Effects

Based on Table 7, the core count exhibited the largest delta value of 3.23, followed by the yarn count with a delta of 3.00, and the take-up rate with a delta of 2.507. These results indicate that core count is the most dominant factor affecting tensile strength, followed by yarn count, whereas take-up rate exerts the smallest influence.

Table 7. Respon tabel S/N Ratio

Level	Core Count	Take Up Rate	Yarn Count
1	0,18	1,364	0,370
2	1,531	0,61	1,381
3	3,418	3,117	3,379

Delta	3,23	2,507	3,00
Rank	1	3	2

Figure 3 shows that increasing the core count from 4 to 9 resulted in a significant improvement in the average S/N ratio, indicating that a higher number of cores leads to greater tensile strength of the braided rope. A similar trend was observed for yarn count, where increasing the yarn size from 6 to 8 also enhanced the tensile strength. In contrast, for the take-up rate factor, the optimum value was obtained at the high level, suggesting that a higher take-up speed produces a denser and stronger rope structure.

Accordingly, the optimum parameter combination based on the S/N ratio analysis is core count at level 3 (9 cores), take-up rate at level 3 (High), and yarn count at level 3 (8). This combination is expected to produce the maximum tensile strength of the braided rope.

4.2. Analysis Of Varians

The objective of the analysis of variance (ANOVA) is to identify the design parameters that significantly influence braiding quality. The results presented in Table 8 indicate that core count has the highest contribution at 35.70%, followed by yarn count (28.94%) and take-up rate (22.18%). The error value of 13.10% suggests that most of the variation in the response can be explained by these three factors. Although the obtained F-values for all parameters were lower than the F-table values, and thus statistically insignificant at the selected confidence level, the practical contributions of core count, yarn count, and take-up rate remain important in improving braiding quality. Among these factors, core count was found to be the most dominant parameter affecting the tensile strength of braided ropes.

Table 8. ANOVA

Faktor	Degree of freedom	Sum of square	Percent Contribution	Mean Square	F-Value
Core Count	2	0.2808	35,7%	0.1404	2,726
Take Up Rate	2	0.174	22,1%	0.088	1,689
Yarn Count	2	0.2269	28,9%	0.113	2,202
Error	2	0.103	13,1%	0.051	
Total	8	0.7847	100%		

4.3. Confirmation Test

The confirmation test was conducted to verify the optimum parameter combination obtained through the Taguchi analysis. Based on the results, the optimum setting was determined at core count level 3, take-up rate level 3, and yarn count level 3. Tensile testing was then performed with three replications to ensure the reliability of the data.

Table 9 Results of the Confirmation Test

Exp	Variabel			Tensile Test Data (kN)			
	Core Count	Take Up Rate	Yarn Count	Replikasi			$\bar{Y}$
				1	2	3	
1	9	High	8	2.224	2.201	2.232	2.219

From the results presented in Table 9, the average tensile strength was obtained as 2.219 kN (221.9 kg). This result indicates that the optimum parameters determined by the Taguchi method were experimentally verified to produce the highest tensile strength compared with other tested combinations. Furthermore, the confirmation test demonstrates that the Taguchi approach is not only effective in reducing the number of experiments but also valid in predicting the process parameters that yield the best product performance.

Accordingly, it can be concluded that the parameter combination of core count level 3, take-up rate level 3, and yarn count level 3 represents the optimum condition, consistent both theoretically and experimentally, for enhancing the tensile strength of braided ropes.

5. CONCLUSION

In this study, based on the results of ANOVA and the S/N ratio graph, it was found that all investigated parameters core count, take-up rate, and yarn count contributed to rope tensile strength, with the greatest effect attributed to core count (35.70%), followed by yarn count (28.94%) and take-up rate (22.18%). A higher core count, faster take-up rate, and larger yarn count resulted in improved rope strength. The optimum parameter combination was determined as core count : 9, take-up rate : high, and yarn count : 8. The confirmation test using these optimum parameters produced a tensile strength of 2.219 kN or 226.29 kg. Disarankan agar penelitian selanjutnya berfokus pada variasi jenis benang dan material inti, karena faktor-faktor tersebut dapat berpengaruh signifikan terhadap kualitas hasil braiding.

ACKNOWLEDGEMENT– The authors would like to express their gratitude to Politeknik Manufaktur Bandung for the support and research facilities provided

REFERENCES

- Kyosev, Y. (2014). *Braiding Technology for textiles*. 1rd edn. Woodhead Publishing. Cambridge.
- Omeroglu, S. (2006). The effect of braiding parameters on the mechanical properties of braided ropes. *Fibres and Textiles in Eastern Europe* **14**, **4**, pp. 53–57.
- Ghamkhar, G., Johari, M. S., & Toudeshky, H. H. (2022). An experimental and theoretical investigation into the effect of braiding angle and combination on a tensile modulus of the tubular biaxial hybrid braids. *Journal of Industrial Textiles*, **51**, **IS**, pp. 822S–841S.
- Soejanto, I. (2009). *Desain Experimen dengan Metode Taguchi*. Graha Ilmu. Yogyakarta.
- Yim, S. (2018). Selection of actuator combination in integrated chassis control using Taguchi method. *International Journal of Automotive Technology*, **19**, 263–270.
- Muttaqin, B. I. A. (2019). Telaah Kajian dan Literature Review Design of Experiment (DoE). *J. Adv. Inf. Ind. Technol.*, **1**(1), 33–40.
- Nosakhare, U. H., & Bright, A. F. (2017). Evaluation of Techniques for Univariate Normality Test Using Monte Carlo Simulation. *Am. J. Theor. Appl. Stat. Spec. Issue Stat. Distrib. Model. Appl. Math.*, **6**(1), 51–61.
- Sintia, I., Pasarella, M. D., & Nohe, D. A. (2022). Perbandingan Tingkat Konsistensi Uji Distribusi Normalitas Pada Kasus Tingkat Pengangguran di Jawa. *Pros. Semin. Nas. Mat. Stat. dan Apl.*, **2**(2), 322–333.
- Del Rosso, S., Iannucci, L., & Curtis, P. T. (2019). Finite element simulation of the braiding process. *Mech. Adv. Mater. Mod. Process.*, **5**(1), 1–11.
- Wulforst, B., Gries, T., & Veit, D. (2014). *Textile Technology: An Introduction*.
- Branscomb, D., Beale, D., & Broughton, R. (2013). New directions in braiding. *J. Eng. Fiber. Fabr.*, **8**(2), 11–24.
- DEM-DOE. *Semin. dan Konf. Nas. IDEC*, November, 1–9.