CNC Parameter Optimization for Leather Batik Production

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ABSTRACT

Batik, recognized as an Intangible Cultural Heritage for Oral and Non-material Culture by UNESCO, continues to attract interest due to its diverse techniques and designs. The demand for batik has expanded beyond fabric to include other mediums such as leather. However, the process of creating batik on leather requires a considerable amount of time, leading to a decline in the number of leather batik craftsmen over time. Therefore, the importance of applying technology in leather batik-making becomes increasingly urgent. One of the technological advancements in batik-making is the use of Computer Numerical Control (CNC) machines. This study aims to find the optimal parameters for a CNC Batik machine in leather batik production using goat leather material. Several parameters were analyzed in this study, including feedrate, wax temperature, and the type of wax used in the batik process. The Taguchi method was applied, utilizing an Orthogonal Array L9 (3^3) design and Grey Relational Analysis (GRA). The results of this study indicate that the optimal combination of parameters for the batik process on leather using CNC batik machines is achieved with a feedrate of 400 mm/minute, a temperature of 80°C, and a wax viscosity of 39.30.

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1. Introduction

Batik has become increasingly popular and rapidly developed since its recognition by UNESCO on October 2, 2009, as an Intangible Cultural Heritage (Masterpiece of the Oral and Intangible Heritage of Humanity). Batik is defined as a handcraft using wax (batik wax) heated as a color barrier with the main tool being a canting, which serves as a container to apply the wax to create specific motifs with meanings (Sutyasmi et al., 2019).

The increasing diversity in batik production techniques and designs has propelled the broader utilization of batik. As a highly valued form of art, batik is now not only confined to textiles but has also been applied to various other mediums such as leather and wood. The continuous development of batik production techniques has led to an increasingly diverse range of batik designs. This support has expanded the market penetration of batik to an international level, with consumers becoming more selective in their demands. As part of fashion trends, consumers are demanding diversification in the use of batik, extending beyond fabrics to other fields such as batik on furniture and genuine leather (Hartati & Khotimah, 2013).

Data from the Indonesian Ministry of Trade shows that exports of leather goods from Indonesia have consistently increased from 2017 to 2021. Despite the Covid-19 pandemic affecting the world in 2019, exports of leather goods remained stable. After the pandemic subsided in 2021, there was a significant surge in export demand. This indicates that leather goods have the potential to become one of the influential non-oil and gas export commodities in boosting the country's foreign exchange reserves and expanding export markets overseas.

According to their production techniques, batik is classified into three types: batik *tulis* (hand-drawn batik), batik cap (stamped batik), and batik *kombinasi* (combination of hand-drawn and stamped batik). Batik *tulis* refers to batik made manually using a canting, while batik cap refers to batik that is hand-stamped. Batik *kombinasi* is the result of combining hand-drawn and stamped techniques (Sutyasmi et al., 2019). Among these three types of batik, batik *tulis* holds the most exclusive value because it requires manual drawing using a canting, thus taking longer to produce compared to other types of batik, but it possesses the highest artistic aesthetic value (SNI 0239, 2014).

However, there are several challenges encountered in producing hand-drawn leather batik crafts, including the lengthy production time required for making hand-drawn leather batik products and the declining number of hand-drawn batik craftsmen over the years. This is due to the decreasing interest of the younger generation, particularly young people, in continuing the tradition, leading to a lack of regeneration.

The leather batik process is now less favored due to its lengthy process and high cost, leading many artisans to switch to eco-print leather techniques. Non-batik techniques such as eco-printing, carving, and stamping are preferred because they offer faster production processes. Therefore, to revive the popularity of leather batik, the application of technology such as CNC machines is needed, aiming to enhance productivity in leather batik production while still maintaining the essence of manual batik-making processes. CNC machines utilize numerical codes to create patterns with wax (batik wax), but the difference from manual batik-making lies in the use of robots as the canting's mover. This technology serves as one solution to the increasing scarcity of manual leather batik artisans, but the process of crafting hand-drawn leather batik crafts must still be preserved.

The study of hand-drawn batik production on fabric using CNC-based machines has been successfully conducted by Kusumawardani (2018). Similar research has been expanded and enhanced through studies focusing on hand-drawn batik machines. Previously, research utilizing hand-drawn batik machines in Butimo has been successfully carried out by Marsel (2019), Mikra (2020), Larasati (2020), Anugerah (2021) and Wibowo (2022). Each researcher has variations in the parameters tested and approaches used.

Research conducted by Kusumawardani (2018) and Mikra (2020) utilized the feedrate variable from the CNC Batik machine's canting as the test factor. Meanwhile, studies conducted by Marsel (2019) and Larasati (2020) employed a combination of two variables consisting of feedrate, wax type, wax temperature, and nozzle size. All of these studies utilized different batik motifs to compare the quality of batik results using CNC machines and hand-made batik, assessed by experts and ANOVA methods. On the other hand, research conducted by Anugerah (2021) utilized the factors of feedrate, wax type, and nozzle size and employed the Taguchi - GRA method to evaluate Batik quality. The research showed that the machine could produce batik faster while maintaining its quality. Wibowo (2022) conducted research using temperature variables with recycled wax used for batik on CNC machines.

Kusumawardani (2018) and Mikra (2020) conducted research using CNC hand-drawn batik on fabric, with the feedrate variable from the CNC batik machine's canting as the sole factor for assessing the quality of the batik results. Additionally, the results obtained from the batik process using CNC machines were faster compared to manual methods, and according to several experts in the field of batik, the overall quality of batik results using CNC batik machines did not differ from conventional hand-drawn batik.

The research conducted by Marsel (2019) aimed to compare the time and quality between hand-drawn manual batik and CNC machines with the Parang Barong motif on fabric using a CNC batik machine. The steps of the process of batik consist of *klowong* and *nembok*. The variables considered were feedrate and wax temperature. The results showed that the *klowong*-making process with CNC machines was faster than manual methods, but the *nembok* process was slower due to the limitations of the canting size on CNC machines and differences in *nembok* techniques. Expert judgment was also conducted to compare the quality of the results between batik made with CNC machines and manually. Although the quality of *klowong* with CNC machines was equivalent to manual methods, *nembok* with CNC machines still needed improvement due to the thin wax layer resulting in less effective wax penetration compared to conventional batik.

The research conducted by Larasati (2020) aimed to design the process of hand-drawn batik making using CNC batik through benchmarking methods. The parameters optimized were the combination of wax temperature and type to achieve the best batik quality. The research results showed that the making batik time for the *klowong* part (main motif) was shorter compared to conventional batik. Additionally, the production cost of making batik using CNC machines was cheaper.

In Anugerah's research (2021), the analyzed parameters were feedrate, wax type, and nozzle size, utilizing an Orthogonal Array L9 (3^4) design, Taguchi method, and ANOVA, conducted separately for the *klowong* and *sawut* processes. The main findings included setting the feedrate at 550 mm/minute, wax type 2, and nozzle size 3 for the *klowong* process, and feedrate 1500 mm/minute, wax type 3, and nozzle size 2 for the *sawut* process. The use of wax in the CNC Batik was higher by 10.08% compared to conventional Batik due to the repetition of feeding movements in the same segment. In Wibowo's research (2022), the parameters used were temperature and utilizing recycled wax on CNC machines. Analysis was conducted using the Taguchi-Grey Relational Analysis and Analysis of Variance on the *klowong* and *nyecek* processes. Comparisons were made regarding batik quality, processing time, wax usage, and energy consumption.

From the literature reviews above, researchers can determine the position of this study. The research focus will be directed towards producing Hand-drawn Batik using CNC Batik machines on leather material. The difference between this research and previous studies lies in the material used for making batik and the parameters analyzed. In previous studies, all research used fabric, while in this study, leather will be innovatively used as the batik material using CNC machines. This research aims to find the optimal parameters to produce batik on leather material.

2. Literature Review

2.1 Conventional Hand-drawn Batik

The batik process is typically carried out using the dye wax resist technique. The dye wax resist technique in hand-drawn batik is a method to create line patterns and dots to form a batik motif using a tool called *canting*. Batik motifs are drawn with heated batik wax so that they can be applied and adhered to the medium used for the batik process using a *canting* (Masiswo *et al*., 2017). In the creating of hand-drawn batik, the wax application is done using a hand-drawn *canting*. The use of a hand-drawn *canting* requires a minimum of 5 years of experience to produce a good batik motif. Batik-making experience is closely related to skill and dexterity, which greatly influences the outcome of hand-drawn batik. These batik wax patterns are what prevent adhesion during dyeing (Akhmad *et al*., 2020).

2.2 Computer Numerical Control Batik Machine (CNC Batik Machine)

CNC is a technology that controls machine tools automatically by employing a microcomputer installed on the machine. CNC machines will operate according to programmed instructions based on numerical code programs. These instructions include machine movement direction, speed, and so on (Keller *et al*., 1982). With CNC machines, operators do not need to control the machine manually, thus enhancing efficiency and precision for most tasks.

The CNC batik machine has been modified from a regular CNC machine to have the ability to transfer batik patterns from the canting to batik media such as fabric, leather, wood, or other media using heated batik wax (Kusumawardani *et al*., 2018). Similar to conventional hand-drawn batik, CNC machines also require a tool that functions to apply wax to the batik media, called a canting. The canting on CNC machines is designed to replace the function of manual canting and moves according to the automatic control of the CNC machine. The canting on CNC machines is made using copper material with different-sized nozzle tips. Just like manual canting, which has pointed ends, the nozzles on CNC machines have sizes for outlining *(nglowong)* and filling (*ngiseni*). A 0.4 mm-sized nozzle is used for drawing the main motif (*nglowong*), while a 0.7 mm-sized nozzle is used for filling (*ngiseni*). The canting on CNC batik machines is equipped with heating elements in the form of nickel-chromium wire wound around the canting tube to maintain the wax temperature stable so that it does not harden. The hot temperature control system used in CNC batik machines consists of a Digital Thermostat, which regulates the temperature on the canting to keep the wax liquid, and a Voltage Regulator, which regulates the electric voltage flowing to the heating elements to adjust the power consumption (Kusumawardani et al., 2018).

The operation of the CNC batik machine uses both the Polar and Cartesian coordinate systems. In the polar coordinate system, the position of a point is defined by its distance from the origin (zero point) and its direction. Meanwhile, the Cartesian coordinate system consists of the X-axis and the Y-axis, where the X-axis represents the horizontal axis and the Y-axis represents the vertical axis. The intersection of the X-axis and the Y-axis is called the origin point or zero point. The position of each point is determined based on its values along the X and Y axes (Kusumawardani, 2018).

2.3 Coreldraw, Inkscape and Artsoft Mach3 software

Several software programs used to support the creation of batik using CNC batik machines include CorelDRAW, Inkscape, and Artsoft Mach3. CorelDRAW is a 2D graphics processing software based on vector graphics used to create batik design drawings. Inkscape is used for vector-based graphic design using Scalable Vector Graphics (SVG) format as its main format. This software supports exporting vector-based designs into G-code for running the CNC batik machine program. Meanwhile, Artsoft Mach3 is software used to control CNC machines, which is useful for controlling the movement of stepper motors and servos on CNC machines through G-code inputs. The operation of Artsoft Mach3 involves transforming images into G-code, which is then used to control the machine.

2.4 Benchmarking

Benchmarking involves emulating the experiences of others who have succeeded to minimize failures, especially within the same field. Benchmarking is recognized as a crucial tool for achieving sustainable quality improvement in industries (Dattakumar & Jagadeesh, 2003). Benchmarking has been widely used and accepted. The results of benchmarking activities are used to adopt best practice standards in order to achieve targeted goals.

2.5 Design of Experiment (DoE) – Taguchi Method

DOE (Design of Experiments) is a systematic method for drawing objective conclusions by identifying factors that can influence the outcome of a process. The main reason for using DOE is to obtain unambiguous results with minimal costs (Whitcomb, 2000). DOE is also used to find the optimal combination of inputs to produce the best output.

One of the Design of Experiments (DOE) that can be used to obtain valid data with fewer experiments is the Taguchi method. Taguchi is employed for problems with numerous experiments and factors, making them complex and time-consuming. Due to this reason, the Orthogonal Array (OA) is used in the Taguchi method to study overall parameters with a smaller number of experiments. In this research, the Taguchi Method of DOE is utilized, where this experimental design aims to find the optimal combination of factor levels. The goal of the Taguchi method is to achieve minimal variation and maximum signal-to-noise ratio (SNR) values. The advantage of the Taguchi Method is the reduced number of experiments conducted.

2.6 Grey Relational Analysis (GRA)

Grey Relational Analysis (GRA) is one of the multi-objective optimization methods that can be applied to CNC batik machines with more than one response with different units (Sharma & Yadava, 2012). With the GRA method, experimental data are normalized from zero to one to address the optimization issues of responses with different units. The GRA method is chosen because it is suitable for incomplete and uncertain experimental data. This condition aligns with the Taguchi method, which only uses a few experimental samples. The combination of GRA-Taguchi methods can complement each other's shortcomings, where Taguchi can minimize the time and resources used, but the generated data information is limited. Meanwhile, GRA complements it by providing meaningful results based on limited data from the Taguchi results. This method can optimize multiple responses by converting values on responses with different units into Grey Relational Grade. The values used in GRA analysis are the SNR values obtained from the Taguchi method calculations. The function of GRA analysis is to minimize the sensitivity of response results to existing variations, thus obtaining robust analysis results.

At the initial stage, data normalization was carried out due to different response units, by converting experimental data into scales in the range of 0 to 1. Data normalization has different formulas according to the characteristics of the target.

- *Smaller is Better*

This method is used if the target response for SNR calculations aims to minimize the value. The normalization formula corresponds to equation 1 below.

$$x_i^*(k) = \frac{\max\left(x_i^0(k)\right) - x_i^0(k)}{\max\left(x_i^0(k)\right) - \min\left(x_i^0(k)\right)} \tag{1}$$

- *Larger is Better*

This method is used if the target response for SNR calculations is aimed at maximizing value. The normalization formula corresponds to Equation 2 below.

$$x_i^*(k) = \frac{x_i^0(k) - \min\left(x_i^0(k)\right)}{\max\left(x_i^0(k)\right) - \min\left(x_i^0(k)\right)} \tag{2}$$

- Grey Relational Coefficient (GR-Coefficient)

The GR-Coefficient converts the data value into a coefficient that can show a relationship of experimental data with the best value of the experiment. The GR-Coefficient is done by calculating the value of Δ_{oi} according to Equation 3.

$$\Delta oi(k) = \left|x_0^*(k) - x_i^0(k)\right| \tag{3}$$

After obtaining the value of Δ_{oi} it is used to calculate the value of the GR-Coefficient according to Equation 4.

$$\xi_i(\mathrm{k}) = \frac{\Delta \min + \zeta \Delta max}{\Delta oi(k) + \zeta \Delta max} \quad (4)$$

- Grey Relational Grade (GR-Grade)

The final step of GRA is to combine the GR-Coefficient values of each response characteristic. The calculation formula of the GR-Coefficient corresponds to equation 5.

$$y_i = \frac{1}{n} \sum_{k=1}^{n} \xi_i(k) \quad (5)$$

2.7 Experimental Response

The responses used in this study are derived from the parameters of Hand-drawn Batik quality based on the Indonesian National Standard (SNI). The responses used are the thickness continuity of lines and overall batik quality assessment. Out of the two responses used, only the line thickness indicator can be defined through quantitative measurement and data processing. There are nine quality indicators for batik *tulis* according to SNI, but only seven can be applied to batik on leather material. The fabric penetration indicator cannot be used in batik on leather media. These seven indicators include line continuity, line neatness, quantity of pattern angles, line thickness continuity, line deviation, overall assessment, and artistic value.

The continuity of line thickness response is calculated using the Standard Deviation between specific points' thickness along the motif line. The response will measure the variation between the values of specific points scattered throughout the motif compared to the average line thickness value across the entire motif. The smaller the variation between the line thickness at specific points and the overall average, the better the line thickness continuity can be concluded to be.

3. Result

To determine the parameters to be used in the leather batik process with CNC machines, a preliminary study is conducted first. The parameters are selected based on their sensitivity to CNC machines. Some of the parameters tested include feedrate, wax temperature, wax viscosity and nozzle type. The conclusions from the preliminary study will then be used for the Design of the Experiment (DoE) using the Taguchi method L9 (3^3) design with 3 factors, each having different levels. The DoE design is then used as a guide in carrying out batik using CNC machines, resulting in 27 experiments. The batik results are then measured to determine the responses to be optimized, including the thickness of the wax lines and overall batik assessment. Subsequently, a combined analysis is conducted aiming to obtain the value of the overall response using the Grey Relational Analysis (GRA) method, considering both wax thickness and overall batik assessment. After obtaining the optimal combination of each factor level, statistical tests and validation by batik experts are conducted in the final stage.

3.1 Preliminary Study

- *Feedrate*

In the batik process, experiments are conducted with variations in feedrate on batik motifs to match the line size created using CNC machines with the results of manual batik. The tested feedrate range is from 200 mm/second to 1300 mm/second, and all experimental results before and after dyeing are attached in Appendix 1.

Table 1. Best feedrate result

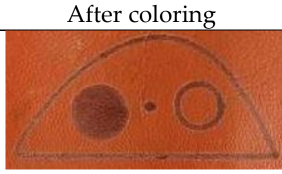
Parameter	Level	Before coloring	After coloring
Feedrate	300		
	400		

Table 1. Best feedrate result (Cont.)

Parameter	Level	Before coloring	After coloring
	500		

It was found that if the batik temperature is too high, it causes the waxed area to darken. Table 1 shows that the optimal feedrate is within the range of 300 mm/second to 500 mm/second, as evaluated by experts batik. According to the experts, the best parameter is when the klowong lines have a similar width to manual batik, are consistent, and not overlapping or interrupted. Therefore, the feedrate limits to be used are 300 mm/second for the lower limit, 400 mm/second for the middle limit, and 500 mm/second for the upper limit. Determining the DoE in the batik process on leather using CNC machines will consider these limits.

- *Wax Temperature*

Experiments with different temperature variations were conducted to achieve results consistent with manual leather batik. Determining the optimal temperature is crucial for the leather being made batik. If the temperature is too high, the leather medium will burn and tend to darken after being melted. Moreover, if the temperature is too high, the wax will be more fluid, causing more wax to come out of the nozzle, resulting in wider lines. Conversely, if the wax temperature is too low, it will produce inconsistent lines (broken lines) because the wax will have difficulty coming out of the nozzle. The temperature variation experiments before and after coloring can be seen in Appendix 2.

Table 2. Best temperature result

Parameter	Level	Before coloring	After coloring
Temperature	80		
	90		
	100		

Based on the assessment from experts, the optimal lower limit temperature is 80°C, the middle limit is 90°C, and the upper limit is 100°C, as shown in Table 2. The best temperature parameters are obtained based on the consideration of the batik results, where the lines widen or not due to the wax being too hot. Additionally, if the wax is too hot, it will cause the leather to burn after melting, which will decrease the quality of the leather batik.

- *Wax Viscosity*

Experiments with different types of wax were conducted to determine the best type of wax to achieve results similar to manual batik on leather. Three types of wax underwent laboratory testing to determine their viscosity values, which would affect the batik process using CNC batik machines. Determining the best wax type also affects the finishing process during wax removal. The results of experiments involving various types of wax with different viscosity values before and after dyeing can be seen in Appendix 3. These three waxes with different viscosity values will be used for the DoE process of batik on leather using CNC machines.

- *Nozzle Type*

In the batik process, experiments were conducted by varying the types of nozzles to achieve line sizes comparable to manual batik. There are 4 types of nozzles available in Butimo, but nozzle number 1 was not used in the experiments because its function is to create "isen-isen" and "sawut". Therefore, in the preliminary study experiment, nozzle 1 was not used because the Buketan motif to be created consisted only of "klowong" lines without "isen-isen" or "sawut". Experiments using several types of nozzles before and after dyeing can be seen in Appendix 4. Based on expert assessment, the use of nozzle numbers 3 and 4 resulted in lines that were too wide and not consistent with manual batik results. From the preliminary study, it can be concluded that the use of nozzle 2 is the best because the line thickness matches that of manual batik.

3.2 Design of Experiment (DoE)

The Design of Experiment (DoE) was conducted using the Taguchi method with an L9 (3^3) design, employing 3 factors with varying levels for each factor. All factor and level variations were determined based on the conclusions drawn from the preliminary study conducted earlier. Each experiment was replicated 3 times to ensure the selection of the best experiment. Thus, the total number of experiments amounted to 27. Appendix 5 contains the Taguchi method design that was created. The experiments were conducted by creating the Buketan batik motif, where all motifs consisted of "klowong" patterns. The results of the Buketan motif experiment drawings after dyeing can be seen in Appendix 6. After all DoE factor experiments were completed, the quality of the batik was assessed using the expert judgment method in the form of a questionnaire given to 3 experts with a minimum of 10 years of experience in batik. The attributes in the questionnaire represent the quality criteria of batik according to the Indonesian National Standard (SNI). The optimal values from the selected factor combinations will be used to produce batik products on leather.

The summary of expert assessments after dyeing is attached in Appendix 7. From the expert evaluations, the combination of the 6th experiment factors was chosen because it received the highest score among the others. The highest score from the experimental factors will be selected from the colored batik results, considering the outcome of this research, which is the production of colored leather batik products. Therefore, the 6th experimental factor, consisting of the combination of Wax Viscosity 39.30 cP, Feedrate 500 mm/second, and Temperature 80°C, will be used to produce leather batik products.

The run order shown in Appendix 5 is then used as a guide in conducting batik production using the CNC batik machine, resulting in 27 experiments. The batik results are then measured to determine the responses to be optimized, including the thickness of the wax lines and the overall assessment of the batik. The measurement data is presented in Appendix 8.

The measurements of line thickness in the DoE batik production process with the CNC batik machine are used for determining optimal factors. Line thickness measurements are conducted using the Dino-Lite Microscope, considering its higher precision level, by measuring the surface of the skin with the batik motif drawn using wax. The characteristic that can be measured is the line thickness represented by the Standard Deviation (SD) value.

3.3 Response Analysis

- *Line Thickness Continuity Response*

This study evaluates the response characteristics of batik production using a CNC batik machine by measuring the continuity of the wax-applied line thickness on the skin surface. Line thickness continuity is represented by the Standard Deviation, which is a measure of data dispersion. The target of this research is to minimize the response, as the smaller the response value, the better the batik quality. Therefore, the Signal Noise Ratio (SNR) characteristic selected is 'Smaller is Better'. Appendix 9 summarizes the calculation of the Standard Deviation values of line thickness from the experiments. The standard deviation values in Appendix 9 will then be processed using the Taguchi method to obtain SNR values using the equation according to the 'Smaller is Better' response target. A summary of the SNR calculation results can be seen in Appendix 10. Next, Taguchi analysis calculations are performed using Minitab Statistical software to generate data for the Signal to Noise Ratio table and Main Effect Plot Graphs of the continuity of line thickness characteristics, as shown in Appendix 11. The delta value indicates the magnitude of the influence of a factor on the experimental response of line thickness continuity. A factor will have a greater impact on the response if the delta value of that factor is larger. The graph shows the relationship between wax viscosity, feedrate, and wax temperature with the continuity of line thickness response.

- *Overall Batik Assessment Response*

The response characteristics of batik production using a CNC batik machine are based on the overall assessment of batik production on the skin. In the overall assessment response characteristic, the measure used to represent this response is the mean, which is a measure of data dispersion. The target of this research is to maximize the response, as the larger the response value, the better the quality of the batik production. Therefore, the Signal Noise Ratio (SNR) characteristic selected is 'Larger is Better'. Appendix 12 summarizes the calculation of the average assessment scores of overall batik production evaluated by experts based on experiments. The average values in Appendix 12 will then be processed using the Taguchi method to obtain SNR values using the equation according to the 'Larger is Better' response target. The summary of the SNR calculation results can be seen in Appendix 13. Next, Taguchi analysis calculations are performed using Minitab Statistical software to generate data for the Signal to Noise Ratio table and Main Effect Plot Graphs of the overall batik production assessment characteristics, as shown in Appendix 14.

3.4 *Combined Analysis – Grey Relational Analysis (GRA)*

Taguchi analysis is used to obtain optimal values for the characteristics of wax thickness and overall assessment of batik production. Meanwhile, the combined analysis aims to obtain the overall response value of both characteristics, namely wax thickness and overall assessment of batik production, using the Grey Relational Analysis (GRA) method.

Before conducting GRA, the response values must first be transformed into S/R ratios. This step has been previously performed above for single-objective optimization purposes. The S/R ratios for wax thickness continuity and overall assessment can be seen in Appendices 10 and 13. The first step in GRA is GR Generation to normalize the data due to different units based on Equation 2 with the 'Larger is Better' characteristic. Detailed results of the GR Generation calculation can be found in Appendix 15. Next is the calculation of GR Coefficients based on Equation 3, followed by the calculation using Equation 4. Detailed calculation results of GR Coefficients can be seen more comprehensively in Appendix 16. After that, the final step of GRA is calculating the GR Grade based on Equation 5, with weighting given to each response according to expert opinions on the importance of the responses. The detailed calculation results of GR Grade can be seen in Appendix 17. The value of the GR Grade will be input into the Taguchi analysis for the overall response. The calculation will use the 'Larger is Better' characteristic because the values in the calculation are the result of transformation from SNR values. The results of the GRA calculation will be optimal values if there are no factors significantly affecting the ANOVA analysis. Therefore, the optimal value of the Taguchi-GRA calculation will be chosen because it can robustly represent the overall response results.

3.5 *Statistical Test of Response*

- *Normality Test*

The normality test aims to determine whether the overall combined response data is normally distributed or not. The results of the normality test on the continuity of line thickness response, overall batik response, and combined GRA response can be seen in Appendix 18. Based on the results of the normality test calculation of the overall response experimental data, all data are normally distributed with p-values above 0.05.

- *Analysis of Variance* (ANOVA)

The ANOVA test analysis of SNR for line thickness continuity, overall batik assessment, and overall GR-Grade indicates results in Appendix 19. Based on the ANOVA test calculations, the p-values of all factors are above 0.05. Thus, there are no factors significantly affecting the experimental response outcomes. In the combined characteristic of overall response, the factors with the largest to smallest contribution percentages are the viscosity of the wax and temperature, and the smallest is the feedrate, respectively.

4. Discussion

4.1 *The selection of optimal levels of Batik on leather materials*

The optimal level values for each factor were obtained based on the Taguchi analysis calculations conducted above. The results of the Taguchi analysis will be combined with the ANOVA test data to determine whether the factors significantly influence the experimental response. ANOVA tests are conducted on each characteristic, namely continuity of line thickness, overall batik assessment, and overall response. Values in the ANOVA table will be considered significant if they have a p-value less than 0.05. The results of each characteristic factor value in the ANOVA test will determine the selection of the optimal level values for the factors. The optimal factor values will follow the highest values in the Taguchi SNR analysis of response characteristics if the ANOVA test results show a significant influence on the response characteristics. However, if the factors do not significantly influence the response characteristics, then the optimal factor values will follow the highest values in the GRA SNR analysis.

Based on the results of Appendix 21, there are no factors significantly affecting the characteristics of line thickness continuity and overall batik due to all calculated p-values > 0.05. Therefore, all factors in determining the optimal level values will refer to the optimal level values calculated from the combined SNR analysis of overall response with GRA. This is because the Taguchi-GRA calculation is designed to produce a robust design that can represent all experimental response results well. Here is a summary of the determination of optimal level values according to Table 3.

Table 3. Optimal Value of Factors

Factors	Level	Value
Wax viscosity (cP)	2	39,30
Feedrate (mm/menit)	2	400
Temperature (^{o}C)	1	80

4.2 Validation Test by Experts in Hand-drawn Batik

The optimal values from the selected factor combinations will be used to create leather batik products. The testing by experts involves three experts in the field of hand-drawn batik. The results of the leather batik process will undergo expert assessment to evaluate the quality of batik with 7 criteria. Expert assessment is conducted on the results of 3 conventional hand-drawn batik leathers and 3 leathers batik using CNC batik machines. Here is a summary of the expert assessment results in Table 4.

Table 4. Summary of Batik Quality Assessment by Experts

Criteria	Conventional			Machine		
	Leather 1	**Leather 2**	**Leather 3**	**Leather 1**	**Leather 2**	**Leather 3**
Line Continuity	3,667	3,667	3,667	4,000	4,000	4,333
Line Neatness	2,667	3,000	2,667	4,000	4,667	4,333
Line Thickness Continuity	3,667	3,333	3,667	3,667	4,000	4,333
Pattern Angle Quality	3,667	3,000	3,333	4,000	3,667	4,000
Line Deviation	2,667	2,667	3,000	4,333	4,667	4,667
Overall Assessment	4,000	3,333	4,000	4,333	4,000	4,667
Artistic Value	4,000	3,667	3,667	4,000	4,000	4,000
Average Leather	3,477	3,238	3,429	4,048	4,143	4,333
Average Process		3,381			4,175	

In Table 4, it is evident that the leather batik results obtained using the CNC batik machine have higher values compared to those produced conventionally. However, to conclude the data, further analysis using ANOVA testing is required to determine if there are significant differences between conventional batik and CNC batik. Before this, a normality test was conducted to assess the data distribution in each group of conventional batik processes and CNC batik, as shown in Appendix 20. The normality test results in Appendix 20 indicate that both conventional batik and CNC batik processes have normally distributed data, with p-values above 0.05. Therefore, ANOVA testing can proceed to ascertain any significant differences between the two batik processes.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Proses	1	0.1092	0.10922	1.4	0.302
Error	4	0.3114	0.07785		
Total	5	1.42060			

Figure 1. Expert Assessment ANOVA Test Results

Based on the ANOVA test results in Figure 1, it is shown that the p-value exceeds 0.05, indicating that there is no significant difference in the quality of batik between the conventional batik process and the batik process using the CNC machine.

4.3 Result of Hand-drawn Batik On LeatherMaterial Using CNC Batik Machine

Based on the calculation of the combination of optimal values that have been obtained, a reference to the optimal value is carried out using a batik CNC machine. The following are the results of batik on leather media using CNC batik machines.

Figure 2. The results of batik on leather material using CNC batik machines

After obtaining the optimal parameters for creating batik on leather material using the CNC batik machine, three replications were made to consistently observe the optimal parameter results of the research. After replicating three times, it resulted in consistently good batik production overall in terms of line continuity and overall batik results. The replication results of batik production produced batik products, as seen in Figure 3.

Figure 3. Leather batik product using CNC Machine Batik

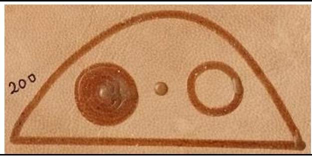
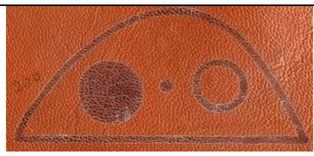
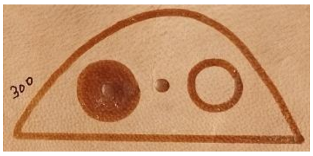
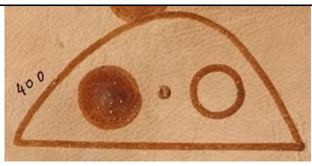
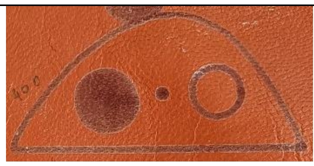
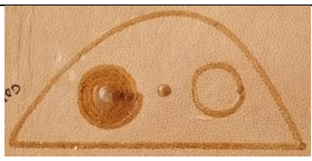
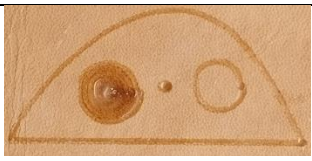
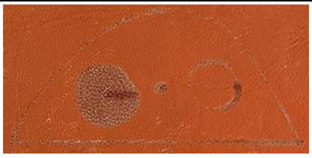
5. Conclusion

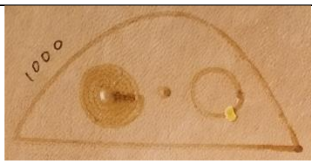
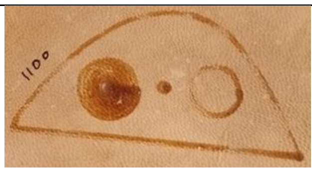
The research results indicate that batik production on leather material has been successfully achieved using the CNC Batik machine. The entire process, including *klowong* motif design and batik process, has been structured following conventional batik procedures through benchmarking. Motif design and G-code generation were digitally performed using CorelDraw X8 and Inkscape software. The machining process was directly controlled via specialized CNC control software, Artsoft Mach3. The optimal parameters applied for batik production on leather material include a feedrate of 400 mm/minute, wax temperature of 80°C, and wax viscosity of 39.30. Validation of these results was conducted by batik experts, demonstrating a high level of conformity with conventional batik.

Some suggestions for further research based on the researcher's experience include the importance of paying attention to the smoothness of the leather to prevent wrinkling during the batik process, as this significantly affects the final batik quality. Furthermore, it is recommended to regularly clean the nozzle, waxing equipment, and canting to prevent blockages and ensure a smooth flow of wax, thus maintaining the continuity of the lines produced. Since the current study uses goat leather, it is also important to conduct further research aimed at studying the interaction between variables such as feedrate, wax type, and wax temperature on other materials such as cowhide or other animal hides, or even on wood surfaces. Additionally, for leather materials, it is advisable to moisten the leather adequately before starting the batik process to reduce scorching when the wax is removed. Furthermore, alternative methods for finding optimal parameters should also be developed to improve the accuracy of the analysis results.

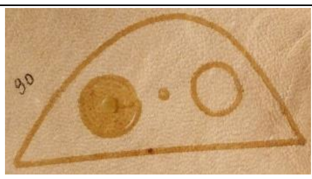
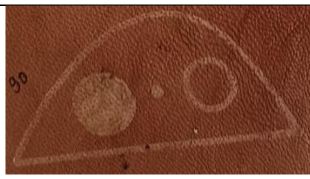
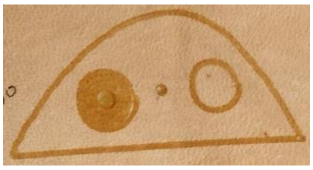
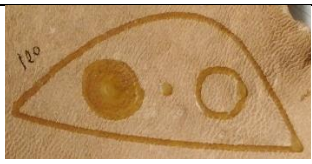
Appendix

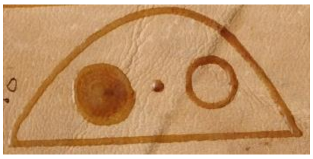
Appendix 1. Variation experiments of feedrate before and after coloring

Parameter	Level	Before Coloring	After Coloring
Feedrate	200		
	300		
	400		
	500		
	600		
	700		
	800		
	900		

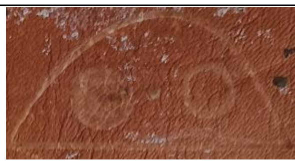
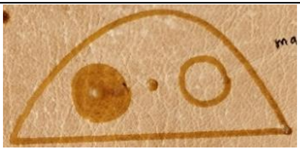
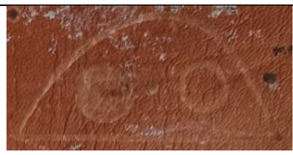
Parameter	Level	Before Coloring	After Coloring
	1000		
	1100		

Appendix 2. Variation experiments of temperature before and after coloring

Parameter	Level	Before coloring	After coloring
Temperature	80		
	90		
	100		
	110		
	120		
	130		
	140		

Parameter	Level	Before coloring	After coloring
	150		

Appendix 3. Variation experiments of wax viscosity before and after coloring

Parameter	Level	Before coloring	After coloring
Wax Viscosity	11,40		
	39,30		
	42,35		

Appendix 4. Variation experiments of wax viscosity before and after coloring

Parameter	Level	Before coloring	After coloring
Nozzle Type	2		
	3		
	4		

Appendix 5. The Taguchi design

Exp	Viscosity	Feedrate	Temperature
1	11.40	300	80
2	11.40	400	90
3	11.40	500	100
4	39.30	300	90
5	39.30	400	100
6	39.30	500	80
7	42.35	300	100
8	42.35	400	80
9	42.35	500	90

Appendix 6. Experimental results after coloring

E	Information	Replication	
1	V=11.40 F=300 S=80	1	
		2	
		3	
2	V=11.40 F=400 S=90	1	
		2	
		3	
3	V=11.40 F=500 S=100	1	
		2	

E	Information	Replication	
		3	
4	V=38.30 F=300 S=90	1	
		2	
		3	
5	V=38.30 F=400 S=100	1	
		2	
		3	
6	V=39.30 F=500 S=80	1	

E	Information	Replication	
		2	
		3	
7	V=42.35 F=300 S=100	1	
		2	
		3	
8	V=42.35 F=400 S=80	1	
		2	
		3	

E	Information	Replication	
9	V=42.35 F=500 S=90	1	
		2	
		3	

Appendix 7. Summary of quality assessment after coloring.

DoE	After coloring			Total
	Expert 1	*Expert* 2	*Expert* 3	
1	3,71	3,47	3,81	3,66
2	3,52	3,28	3,57	3,46
3	2,90	2,71	2,67	2,76
4	4	3,05	3,71	3,59
5	4,43	3,24	3,62	3,76
6	3,90	3,62	4,05	**3,86**
7	3,76	3,76	3,57	3,70
8	3,38	3,71	3,43	3,51
9	3,29	3,71	3,71	3,57
Total	3,65	3,39	3,57	**3,54**

Appendix 8. Line thickness measurement data.

Exp	Line Thickness (mm)		
	Replication 1	Replication 2	Replication 3
1	1.179	1.383	1.236
2	1.199	1.216	1.174
3	1.319	1.311	1.318
4	1.313	1.294	1.311
5	1.281	1.303	1.291
6	1.154	1.181	1.195
7	1.525	1.375	1.583
8	1.269	1.179	1.260
9	1.329	1.240	1.265

Appendix 9. Standard Deviation of Line Thickness

Exp	Rep 1	Rep 2	Rep 3	Avg
1	0,060	0,188	0,084	0,111
2	0,084	0,064	0,138	0,095
3	0,062	0,082	0,256	0,133
4	0,084	0,039	0,074	0,065
5	0,127	0,067	0,072	0,089
6	0,097	0,057	0,056	0,070
7	0,074	0,076	0,048	0,066
8	0,057	0,087	0,092	0,079
9	0,059	0,119	0,076	0,085

Appendix 10. Line Thickness SNR Calculation

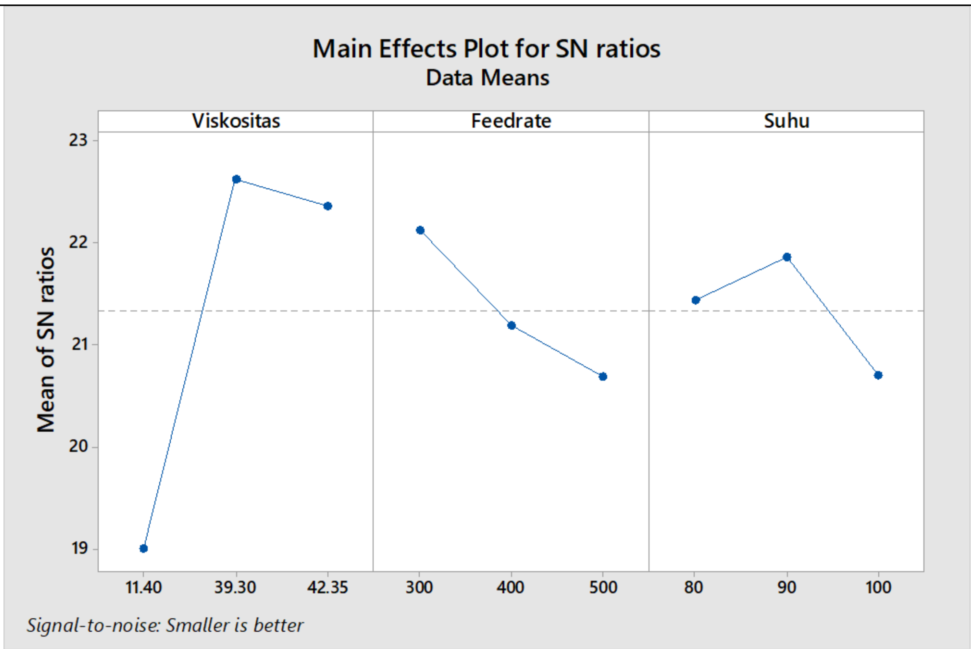
Exp	S/R Ratio Line Thickness
1	18,13
2	19,97
3	15,96
4	23,34
5	20,67
6	22,78
7	23,40
8	21,91
9	21,06

Appendix 11. Response SNRTable Standard Deviation & Main Effect Plot Continuity Thickness Line

Response Table for Signal to Noise Ratios

Smaller is better

Level	Viskositas	Feedrate	Suhu
1	19.01	22.13	21.44
2	22.62	21.18	21.85
3	22.36	20.68	20.71
Delta	3.61	1.44	1.15
Rank	1	2	3



Appendix 12. Average Overall Assessment of Batik

Exp	Rep 1	Rep 2	Rep 3	Avg
1	3,667	3,333	3,000	3,333
2	3,000	3,667	3,333	3,333
3	2,667	3,000	3,000	2,889
4	3,333	3,667	3,667	3,556
5	4,000	3,667	4,333	4,000
6	4,000	4,000	4,333	4,111
7	3,333	3,667	3,333	3,444
8	3,667	3,333	4,000	3,667
9	3,667	3,333	3,333	3,444

Appendix 13. Calculation of SNR Overall Assessment Batik

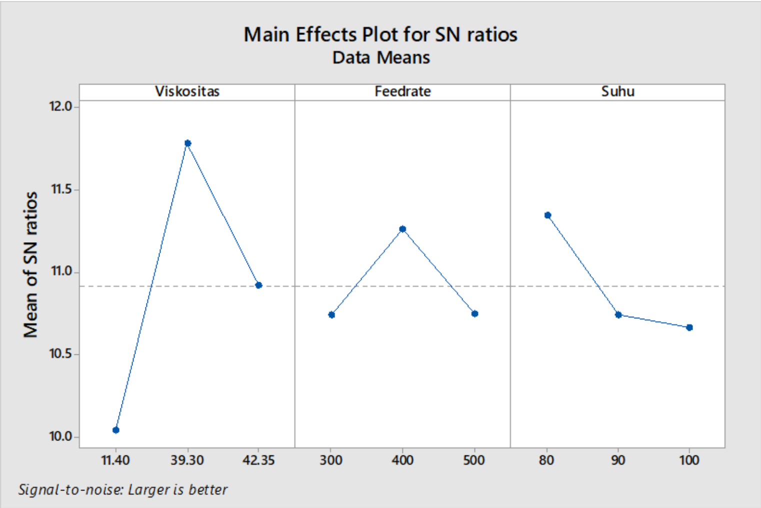
Exp	S/R Ratio Overall Assessment Batik
1	10,370
2	10,370
3	9,174
4	10,992
5	11,981
6	12,261
7	10,716
8	11,213
9	10,716

Appendix 14. Response Table SNR & Main Effect Plot Average Overall Batik

Response Table for Signal to Noise Ratios

Larger is better

Level	Viskositas	Feedrate	Suhu
1	10.04	10.74	11.34
2	11.78	11.26	10.74
3	10.92	10.75	10.67
Delta	1.74	0.52	0.67
Rank	1	3	2



Appendix 15. GR-Generation Result

Exp	GR-Generation	
	Line Thickness Continuity	Overall Assessment
1	0,292	0,388
2	0,539	0,388
3	0,000	0,000
4	0,991	0,589
5	0,633	0,909
6	0,917	1,000
7	1,000	0,500
8	0,800	0,661
9	0,686	0,500

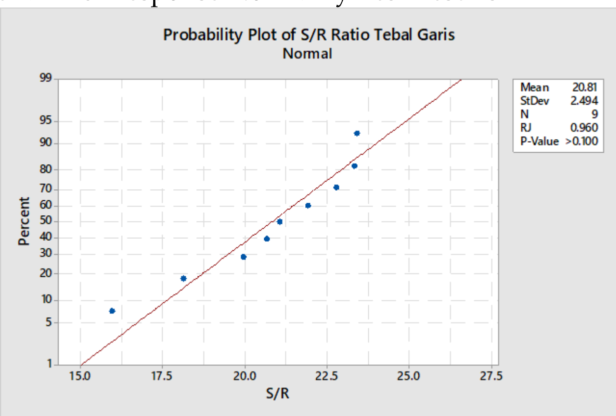
Appendix 16. GR-Coefficient Result

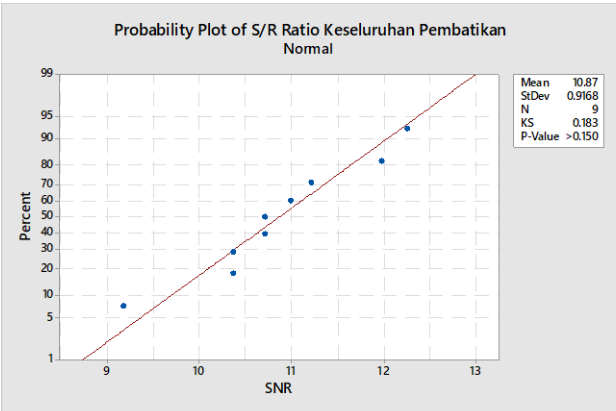
Exp	GR-Coefficient	
	Line Thickness Continuity	Overall Assessment
1	0,414	0,449
2	0,520	0,449
3	0,333	0,333
4	0,983	0,549
5	0,576	0,846
6	0,857	1,000
7	1,000	0,500
8	0,714	0,596
9	0,614	0,500

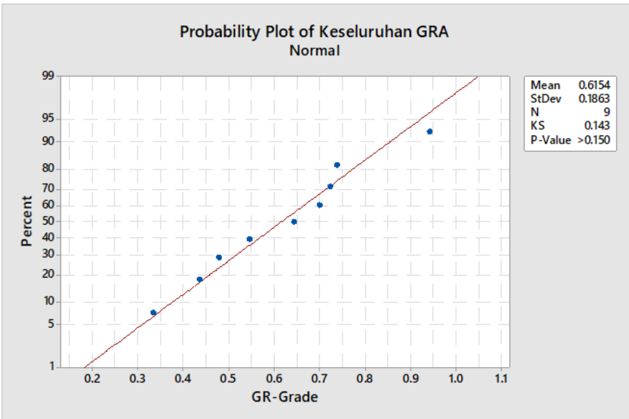
Appendix 17. GR-Grade Result

Eksperimen	GR-*Grade*
1	0,435
2	0,478
3	0,333
4	0,723
5	0,738
6	0,943
7	0,700
8	0,643
9	0,546

Appendix 18. Response Normality Test Results







Appendix 19. ANOVA SNR Test Results

1. ANOVA SNR Continuity Line Thickness Test Results

Analysis of Variance

Source	Df	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Viskositas	2	34.920	70.18%	34.920	17.460	4.770	0.173
Feedrate	2	4.288	8.62%	4.288	2.144	0.59	0.631
Suhu	2	3.232	6.50%	3.232	1.616	0.44	0.694
Error	2	7.318	14.71%	7.318	3.659		
Total	8	49.759	100.00%				

2. ANOVA SNR Overall Assessment Batik Test Results

Analysis of Variance

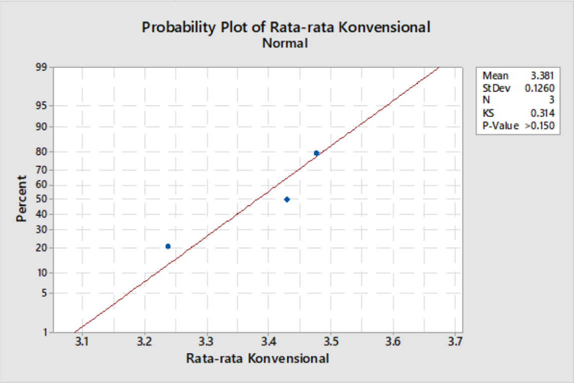
Source	Df	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Viskositas	2	4.7160	70.14%	4.7160	2.3580	6.24	0.138
Feedrate	2	0.4677	6.96%	0.4677	0.2338	0.62	0.618
Suhu	2	0.7840	11.66%	0.7840	0.3920	1.04	0.491
Error	2	0.7560	11.24%	0.7560	0.3780		
Total	8	6.7237	100.00%				

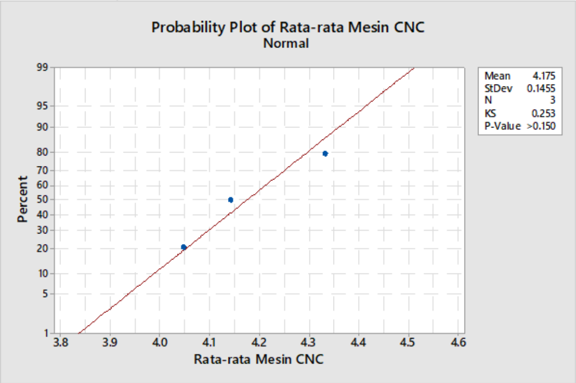
3. ANOVA SNR Overall GR-Grade

Analysis of Variance

Source	Df	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Viskositas	2	0.224260	80.76%	0.224260	0.112130	5.95	0.144
Feedrate	2	0.000299	0.11%	0.000299	0.000149	0.01	0.992
Suhu	2	0.015430	5.56%	0.015430	0.007715	0.41	0.710
Error	2	0.037688	13.57%	0.037688	0.018844		
Total	8	0.277677	100.00%				

Appendix 20. Normality Test Results for Conventional Batik Making and CNC Machines





Appendix 21. Summary of ANOVA Test Result

Characteristics	Significant Effect (p-*value* < 0.05)	Has No Significant (p-*value* > 0.05)
Line Thickness Continuity	-	Wax viscosity
	-	*Feedrate*
	-	Wax Temperature
Overall Assessment of Batik	-	Wax viscosity
	-	*Feedrate*
	-	Wax Temperature
Overall combination (GRA)	-	Wax viscosity
	-	*Feedrate*
	-	Wax Temperature

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