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Implementation of Response Surface Methods for Process Parameters Optimization in Laminated Wood Manufacturing

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***Abstract*—Wood is one of the main ingredients in making furniture. However, the faster the furniture industry in Indonesia cannot improve. Therefore, applying fast-growing wood and starting to be small diameter is applied. But the weakness of this wood will decrease and its size is relatively small. Innovation in overcoming the quality of wood which decreases and the small size, the lamination process is carried out for several types of wood or wood to make a larger size. In this process the wood is glued using glue and pressed with a certain temperature and temperature to produce good quality. Besides being able to glue well and make a larger dimension of wood, it is also expected to increase the density of wood after this lamination process. However, a failure occurred in this lamination process. Such damage can cause structural damage to the product being made. If the damage caused is not attached to the wood properly, it is necessary to vary the appropriate parameters on the lamination machine in order to increase the adhesion of the lamina wood. This study aims to find the optimal value that connects the parameters of the lamination process and response. Parameters - equations that connect parameters and responses are determined by the response surface method using input results of experimental data with a variety of parameter variations. The analysis shows that the lamination process has an influence on the density of wood formations, shown in a combination of temperature parameters 42 C, heating time 160 seconds, pressure 780 psi. the optimum response value of 0.005 gr / mm3.**

Keywords—density, lamination, optimization, response surface.

I. Introduction

Lamina or glulam wood is a board that is glued together with certain glue together with the direction of parallel fibers into one board unit. Laminated wood is made from relatively small pieces of wood made into new, more homogeneous products with a cross section of wood that can be made wider and taller and can be used for construction materials. Laminated beams have advantages compared to ordinary sawn wood, in addition to high strength can be made of a larger cross section and longer. In addition, low quality wood can be used so that the use of wood is more efficient. Machines or tools that are commonly used in the wood lamina process are high frequency laminating machines and rotary wood lamination machines. One of the qualities in lamina wood is specific gravity. Wood specific gravity is generally closely related to wood strength, the higher the wood specific gravity, the higher the wood strength. Good, laminated wood has a strong adhesive percentage of more than 50 percent. To reduce the failure of the connection process, special attention is needed especially on the lamina process on the wood lamination machine.

Therefore, it is necessary to have an appropriate experimental design to identify the process parameters in the manufacture of laminated wood to provide optimum density. The experimental design method is the main basis in engineering activities. In this case the optimization parameters that become the research are pressing pressure, temperature, and heating time to the response of specific gravity in wood laminated products.

Many experiments are required for conventional techniques, and such the methods do not represent the combined effect. It also requires more data to determine the optimum level and take prolonged time, which is unreliable [1,2]. The primary purpose of the experimental design technique is to understand the interactions among the parameters, which could help in the optimization of experimental parameters and provide statistical models [3,4].

The method often used for parameter optimization is the response surface. The methodology based on RSM was found to be convenient because a model can be generated with minimum process knowledge which leads to save time and cost of experimental work. Model developed using RSM are accurate only for a narrow range of input process parameters. Alternatively, the development of higher order RSM models requires a larger number of experiments to be performed. This is the limitation on the use of RSM models for highly non-linear processes, such as burnishing. These constraints have led to the model development based on artificial neural networks [5,6].

This study seeks to find equations that link the parameters of the lamination process and response. Equations that connect parameters and responses are determined by the response surface method by using the input results of experimental data with various parameter variations. The response that will be sought is the quality of the results of the adhesive sticks laminated wood with the optimal value of the density of wood connection.

II. Literature Review

A. Laminated Wood

Laminated wood or also called compound beams is a beam obtained from the process of gluing wood, can be straight, curved or a combination of both. Based on the Indonesian National Standard (SNI) in 2006, wood formed or laminated is sawn wood or wood products that are worked in such a way that all surfaces are smooth and one or more longitudinal surfaces have a fund flow, maximum water content of 16 percent and have the purpose of end use which clear [7]. That laminated wood is made from relatively small pieces of wood made into new products that are more homogeneous with a cross section of wood that is made to be bigger and taller and can be used as construction material [8].

B. Density of Lamina Wood

Wood specific gravity test is done by observing the properties of wood associated with lamination. Wood specific gravity is generally closely related to wood strength. The specific gravity of wood varies according to the difference in wood structure and the ratio between the number of cell walls and wood cell cavities. For testing procedures are as follows:

- Weigh the wood mass using the scales, observe and record the wood mass that appears.
- Measure the dimensions of the formed wood and determine its volume.
- Calculate the density of wood using the calculation below.

$$BJ = (\text{Formed Wood Weight}) / (\text{Wood Volume}) \quad (1)$$

C. Design of Experiment

Design of Experiments or experimental design is a technique used to guide the selection of experiments to be carried out in the most efficient manner. Experimental Design is an experiment conducted to study or discover something about existing processes or compare the effects of several conditions on a phenomenon [2,9]. In doing a DoE, it is necessary to define the problem and choose a variable or what is called a parameter factor. And the number of variables assumed in DoE is limited or assumed to be small. The instructions in conducting an experimental design are as follows:

- Recognition and statement of the problem
- Make a selection of response variables
- Choose factors, levels and ranges
- Choose an experimental design
- Carry out experiments
- Statistical analysis of data
- Conclusions and recommendations

D. Response Surface Method (RSM)

Response Surface Method (RSM) or surface response method is a collection of statistical and mathematical techniques that are useful for developing, improving, and optimizing processes. RSM method is suitable for fitting a quadratic surface and it helps to optimize the process parameters with a minimum number of experiments, as well as to analyze the interaction between the parameters. This method also has important applications in the design, development and formulation of new products, as well as improving the design of existing products [10]. RSM is a statistical method that uses quantitative data from the related experiment to determine regression model and to optimize a response (output variable) which is influenced by several independent variables (input variables) [11].

Myers states that the surface response method is useful as a solution to various problems. In general problem is divided into three categories, namely:

1. Mapping surface responses to an area.
2. Optimization of responses. In the industrial world a very important problem is determining conditions that optimize response.
3. Selection of operating conditions to achieve specifications. In most surface response problems there are several responses that must be considered simultaneously.

Basically the surface response analysis is similar to a regression analysis that uses the procedure for estimating the response function parameters based on the least square (Least Square Method). The difference with linear regression is that in response surface analysis is expanded by applying mathematical techniques to determine the optimum points in order to determine the optimum response (maximum or minimum) [12].

RSM determines the suitable approach for the correct functional relationship between the response variable, y and a set of independent variables, x. When the predicted surface result is an approximation approaching the correct response function, the result will be more or less equivalent to the analysis of the actual system. This method is used to produce dynamic optimum conditions. This method is used to model and analyze a response y that is influenced by several independent variables or x factors in order to optimize the response. The relationship between response y and the independent variable x is:

$$Y = \beta\ (X1, X2, ..., Xi) + \varepsilon \tag{2}$$

With:

Y = Response variable
Xi = Free variable / factor (i = 1,2,3, ... k)
ε = Error
β = Variable model

The relationship between responses and independent variables can be searched using the first order and second-order models, where the first-order model is used to find the optimal region and the second-order model is used to find the optimal point. The relationship between response and independent variables for the first order model can be written as follows:

$$Y = b_0 + \sum_{i=1}^{k} b_i X_i \tag{3}$$

With:

Y = Response variable
b0 = Interception
bi = Model parameter coefficients
Xi = Free variable

In the second-order experimental design there are at least three levels for each factor. Meanwhile, for the second order model equation can be written as follows:

$$Y = b_0 + \sum_{i=1}^{k} b_i X_i + \sum_{i=1}^{k} b_{ii} X_i^2 + \sum\sum_{i<j} b_{ij} X_i X_j \tag{4}$$

With:

Y = Response variable
bi = Regression coefficient (i = 0,1,2,3 ..)
Xi = Variable Independent (i = 1,2,3 ..)

III. METODOLOGY AND IMPLEMENTATION

The products which are the object of research are laminated wood products with elongated joints and the type of joints is finger joints. The variables used are the response variable and the predictor variable. Response variable is a quality characteristic that will be studied, namely the density of wood. the higher the density value of wood joints can produce good and strong furniture structures to improve the quality of its products.

Predictor variables are variables that can be changed in order to see the relationship of the research object under study. In this study the predictor variables used were heating temperature, pressing pressure, and heating time. Variable of content that has been determined then the design level is determined, the level and the factors obtained are as follows:

TABLE I. FREE VARIABLES AND CONTROL LEVELS

Parameters	Temperature (°C)	Heating time (Sec)	Pressure (Psi)
Level 1	37	120	780
Level 2	42	140	800
Level 3	47	160	820

The research design is obtained from the parameters that have been determined at a level then made a design that will be used as a reference in conducting experiments, in making this design the Minitab software is used using the Benhken response surface box design. The results of the design are as shown in table 2 below:

TABLE II. EXPERIMENTAL IMPLEMENTATION VARIABLE

No	Temperature (°C)	Heating Time (Sec)	Pressure (Psi)
1	37	120	800
2	47	120	800
3	37	160	800
4	47	160	800
5	37	140	780
6	47	140	780
7	37	140	820
8	47	140	820
9	42	120	780
10	42	160	780
11	42	120	820
12	42	160	820
13	42	140	800
14	42	140	800
15	42	140	800

A. Data Retrieval

Data collection is carried out by doing the lamination process with different pressure, which is 780 psi, 800 psi and 820 psi. As well as a variety of heating temperatures as well, namely 37 Celsius, 42 Celsius and 47 Celsius. in addition to the difference in temperature and pressure will do variations in the heating time during the lamination process, namely 120 seconds, 140 seconds and 160 seconds last. After conducting the lamination process with three different parameters, the next process is to calculate the density of wood.

B. Hypothesis Testing

1) Influence temperature on the density of wood

- $H0_1$ = There is no effect of temperature on thedensity of wood.
- $H1_1$ = There is an effect of temperature on thedensity of wood.

2) Influence of heating time on wood density

- $H0_2$ = There is no effect of heating time on thedensity of wood.

  $H1_2$ = There is an influence of heating time on thedensity of wood.

3) Influence pressure on the density of wood

- H0$_3$ = There is no effect of pressure on the density of wood.
- H1$_3$ = There is a connection effect on the density of wood.

IV. Results and Discussion

The results of this experiment are as shown in table 3, all experiments were carried out consecutively with three replicas to obtain various results. Then do the average calculation of the three replicas to get the real response value.

TABLE III. EXPERIMENT RESULTS DATA

Temp (° C)	HT (Sec)	Press (Psi)	A	B	C	average (gr / mm3)
37	120	800	0,00050	0.00054	0,00055	0.000536
47	120	800	0,00049	0.00056	0.00053	0.000533
37	160	800	0.00057	0.00054	0.00056	0.000562
47	160	800	0,00055	0.00058	0,00055	0,000564
37	140	780	0.00052	0,00059	0.00053	0.000548
47	140	780	0.00052	0,00060	0.00051	0.000547
37	140	820	0.00053	0.00053	0.00056	0.000544
47	140	820	0.00052	0,00060	0.00052	0,000552
42	120	780	0.00052	0.00054	0,00050	0.000525
42	160	780	0.00121	0,00050	0.00053	0,000749
42	120	820	0,00061	0.00053	0,00047	0.000543
42	160	820	0.00058	0,00065	0.00058	0,000610
42	140	800	0,00060	0,00064	0.00059	0.000613
42	140	800	0,00062	0,00063	0,00058	0,000611
42	140	800	0,00061	0.00071	0.00052	0,000618

A. Surface Regression

The experimental results obtained were then analyzed using Minitab software. The first test is to do surface regression analysis to find out how influential the parameters are on the response. The confidence interval used in this studyis 0.05, so in order to get the parameter measured, the value ofP value must be less than α. The output of the Minitab can beseen that Heating Time has an influence on the response, witha P value (0.032) < α [13] (figure 1).

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	0.000000	0.000000	2.36	0.178
Linear	3	0.000000	0.000000	3.22	0.120
Temp (°C)	1	0.000000	0.000000	0.00	0.956
HT (Sec)	1	0.000000	0.000000	8.64	0.032
Press (Psi)	1	0.000000	0.000000	1.02	0.360

Fig. 1. Experiment results data.

With the percentage of suitability of the model approaching 100% so that it can be concluded that the model is of good quality (See in table 4).

TABLE IV. EXPERIMENT RESULTS DATA

S	R-sq	R-sq(adj)	R-sq(pred)
0.0000419	80.96%	46.70%	0.00%

B. Contour and Surface Plot

Responses can be displayed graphically or in 3-dimensional form with the aim to provide a visualization of the form of the response. Each contour has a different color and size according to the response produced. Whereas surface plot is a projection of contour plot in 3-dimensional form. Component heads identify the different components of your paper and are not topically subordinate to each other. Examples include Acknowledgments and References and, for these, the correct style to use is "Heading 5". Use "figure caption" for your Figure captions, and "table head" for your table title. Run-in heads, such as "Abstract", will require you to apply a style (in this case, italic) in addition to the style provided by the drop-down menu to differentiate the head from the text.

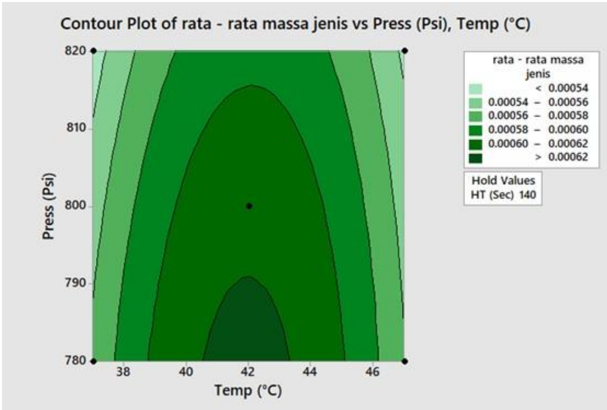

Fig. 2. Contour plot.

The contour plot figure 2 above shows curved contours because the model contains a statistically significant quadratic term. The highest-ranking value for the response of sticky strong percentage is in the middle bottom of the plot, which corresponds to the Temperature and Pressure values. The lowest ranking values for the response of sticky strong percentages are on the left and right sides of the plot, which corresponds to low values of both pressure and temperature. The third predictor, Heating Time, is not displayed in the plot. The value of Heating Time is constant when calculating the response value used to calculate the percentage of density.

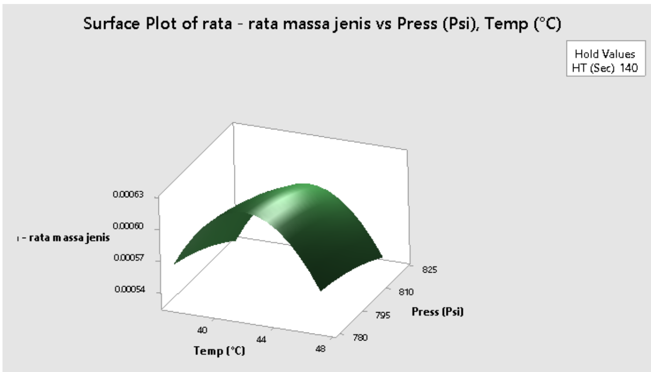

Fig. 3. Surface plot.

In Figure 3 illustrates a surface plot where not always the greater the parameter settings given will give an even greater density response. In the picture describes the parameter configuration that produces the highest response is the second level temperature setting with a parameter setting of 44 Celsius, with a compressive force of less than 790 Psi at the level 2 parameter setting. With this arrangement it can produce a density of 0,00063.

C. Identical Assumption Test

Assumption test can be known by making a plot between residuals and ŷ estimates. If the plot does not show up or down (the residual value spreads randomly) then it can be interpreted that the residuals are identical. The results of identical analysis are shown in Figure 4 below:

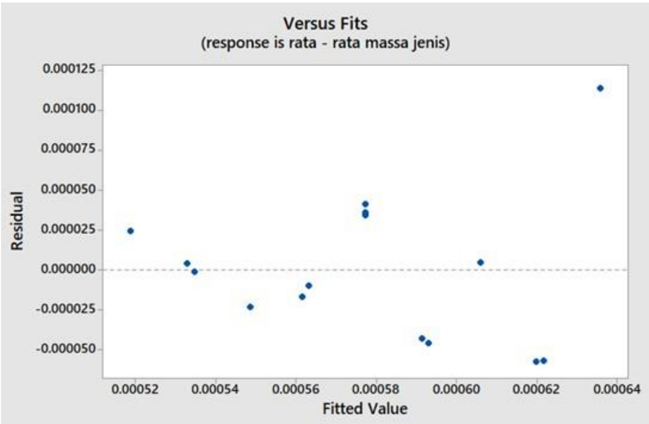

Fig. 4. Identical assumptions.

In Figure 4 above it can be explained that the residual value spread randomly does not tend to go up or down so that the residuals are identical.

D. Independent Assumption Test

The results of independent testing if there is no lag out of the significant limit shows that the independent assumptions are met. As shown in Figure 5 as follows:

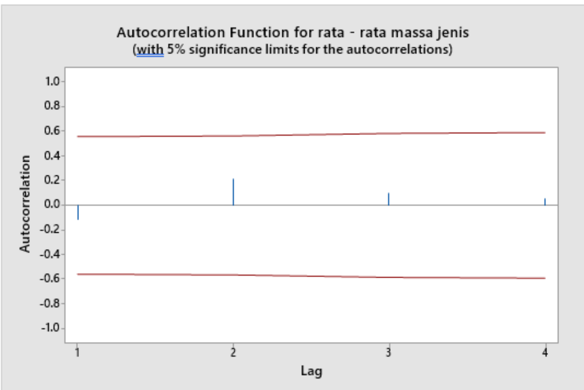

Fig. 5. Autocorrelation graph.

Figure 5 shows that there is no lag (blue line) that crosses the significant limit (red line) so that independent assumptions are met.

E. Normal Distribution Test

Score α (significance level) used in this study was 0.05. The results of the distribution test are shown in Figure 6.

As noted in Figure 6 that the Kolmogorov-smirnov test produces a P value of 0.011. So it can show that the value of P value is smaller than α so the decision that can be taken is rejected H0 which means the residuals are not normally distributed. As a result of residuals that are not normally distributed is because the data contained in this density response test has a value close to zero (0) so that the distribution of data will experience skewness to the right and left.

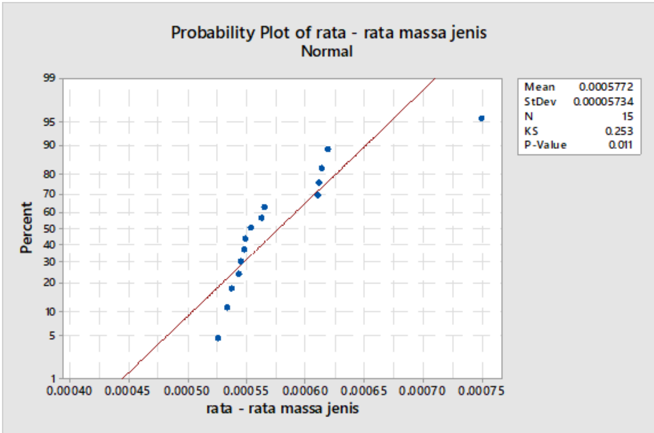

Fig. 6. Probability plot.

F. Response Optimization

In the figure 7, it can be explained that based on the Minitab output, a combination of temperature is 42 Celsius, 160 seconds of heating time, 780 Psi with composite desirability of 0,80051 is obtained.

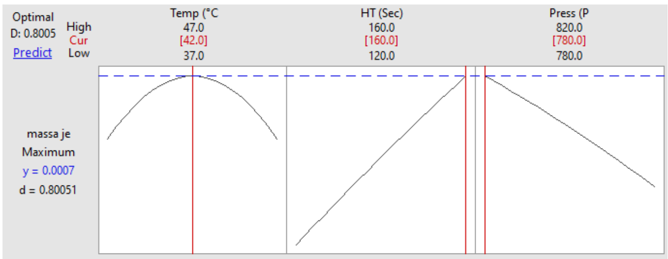

Fig. 7. Experiment implementation variables.

For the optimum response obtained is calculated by the following equation:

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_4X^2 + b_5{X_2}^2 + b_6{X_3}^2$$

Y = 0.183 + (- 9.95E-06 x 42) + (3.42E-06 x 160) + (-2.28E-3 x 780) + (1.06E-08 x (42 ^ 2)) + (-2.23E-09) x (160 ^ 2)) + (-5.24E-11 x (780 ^ 2))

$Y = 0.005211093$ gr / mm3

V. CONCLUSION

Response surface can be used in parameter design applications to optimize parameter settings in the machining process, the purpose of this optimization is to improve machine performance in order to produce good quality products.

In the density response there is also one parameter that has an influence on the response, namely the heating time parameter with a value of 0.032 P value or P value < α, so the heating time parameter is stated to fulfill the hypothesis acceptance requirements and statistically it can be stated that the parameter has an influence on the density response. For temperature and press parameters, the P value is more than α, so it states that the parameter has no response to density.

The results of the analysis show that the lamination process has an influence on the density of wood formations, shown in a combination of temperature parameters 42 Celsius, 160 Seconds heating time, pressure 780 psi. With a response value of 0.005 gr / mm3.

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