The Effect of Gurdi Process Prameter and Fiber Variation On The Delamination of Banana Stem Fiber Composites

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Abstrak.
Delamination is one of the main defects that often occur in the process of curving composite materials and can degrade the quality of the hole as well as the integrity of the joint structure. Banana stem fiber-reinforced thermoplastic composites have the potential to be an environmentally friendly material, but they are still susceptible to delamination due to the influence of the processing process parameters and variations in fiber composition. This study aims to analyze the influence of drill bit diameter, feed rate, drill bit tip angle, fiber arrangement, and cooling medium on delamination at the entrance and exit sides of the banana stem fiber composite hole. The research method used was an experiment with the design of the Taguchi Orthogonal Array L27, while the data analysis was carried out using Signal-to-Noise Ratio (S/N Ratio) with characteristics of Smaller-The-Better and Analysis of Variance (ANOVA) at a constant spindle rotation of 500 rpm. The results showed that the addition of banana stem fiber was able to increase the tensile strength of composites by 61.7% compared to pure thermoplastics. ANOVA analysis showed that on the inlet side delamination, the drill bit diameter, feeding motion, and cooling medium had a significant effect, while on the exit side, the drill bit diameter and drill bit tip angle were the most dominant parameters. Overall, the drill bit diameter is the factor that has the greatest influence on minimizing delamination so that it is the main parameter that needs to be optimized to improve the quality of the hole from the drill in the thermoplastic composite reinforced with banana stem fiber.
Keywords: *thermoplastic composite, banana stem fiber, delamination, gurdging process, Taguchi method, ANOVA and Signal-to-Noise Ratio.*

I. INTRODUCTION

Natural fiber-based composites are increasingly being developed as an alternative to engineered materials because they have advantages in the form of low density, high specific strength, relatively low production costs, and are more environmentally friendly than synthetic fiber-based composites. The use of natural fibers also supports the concept of green manufacturing and sustainability through the use of agricultural waste into value-added materials [1], [2]. One of the natural fibers that has great potential as a reinforcing material is banana stem fiber because it is abundant, easy to obtain, and has good enough mechanical properties for light structural applications [3].

In the manufacturing process of composite components, drilling is an unavoidable process because most mechanical joints using bolts or rivets require holes as a connecting medium. However, composite structures that are anisotropic and layered cause the gurdging process to often produce damage in the form of fiber pull-out, matrix cracks, rough surfaces, and delamination on the inlet and exit sides of the hole [4]. Delamination is the most critical damage because it causes a reduction in effective cross-sectional area, decreases joint strength, and accelerates structural failure during loading [5]. Therefore, the control of the gurdging parameters is a very important aspect to improve the quality of the hole and maintain the integrity of the composite structure.

Various studies show that the quality of the cutting results is influenced by cutting parameters such as rotation speed, feeding rate, drill bit diameter, drill bit tip angle, chisel type, and coolant type [6], [7]. In addition to the process parameters, the internal characteristics of the composite such as the orientation of the fibers, the stacking sequence, the fraction of the fiber volume, and the interface bond between the fiber and the matrix also affect the formation of delamination [8]. However, the relationship between the fiber composition of banana stems and the delamination characteristics during the gurdiation process is still not comprehensively understood.

Previous research has extensively discussed the optimization of dwarfing parameters in various types of composites. Santhanam and Chandrasekaran [9] report that feeding rate is the most dominant factor affecting hole quality in banana–glass fiber hybrid composites compared to rotation speed. Patel et al. [10] showed that the combination of low feed, rotational speed, and a specific drill bit tip angle was able to reduce the delamination factor in banana fiber-reinforced polyester composites. Zulkarnain et al. [11] revealed that the distance between fibers in pineapple leaf fiber composites affects the value of delamination factors so that fiber distribution is an important parameter in the quality of drilling results. Furthermore, Yasin [12] proved that the number of reinforcing layers, gurdi diameter, and feeding rate significantly affected delamination, while optimization using the Taguchi method was able to reduce delamination by up to 10.5%. Recent research by Elhadi et al. [13] shows that the use of Response Surface Methodology (RSM) is able to accurately predict the quality of drilling results with optimal parameters in the form of rotational speed and low feeding rate.

However, most previous research has focused more on optimizing cutting parameters such as rotational speed, feeding rate, drill bit diameter, or chisel type. Research on the effect of the fiber arrangement of banana stems on the formation of delamination, especially on the inlet and exit sides of the hole, is still relatively limited. In addition, studies that combine variations in fiber composition with process parameters using the Taguchi method based on Signal-to-Noise Ratio (S/N Ratio) and Analysis of Variance (ANOVA) to determine optimal parameters are also still rarely reported. This condition shows that there is a research gap, namely the lack of studies that systematically evaluate the contribution of fiber composition to the formation of delamination in thermoplastic composites reinforced with banana stem fibers using a statistical optimization approach.

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Based on the gap in the study, this study aims to analyze the influence of drill bit diameter, feeding motion, drill bit tip angle, type of coolant, and especially the arrangement of banana stem fibers on the delamination on the inlet and exit sides of the results of thermoplastic composite shading with banana stem fiber. Parameter optimization is carried out using the Taguchi method through Signal-to-Noise Ratio and ANOVA analysis so that a combination of process parameters can be obtained that results in minimum delamination.

The study argues that the arrangement of the fibers not only affects the stress distribution around the hole, but also determines the mechanism of crack propagation between layers during the drilling process. With the right orientation of the fibers and the optimal combination of cutting parameters, the thrust force can be reduced so that the tendency for delamination is smaller.

Therefore, evaluation of the effect of fiber arrangement needs to be carried out quantitatively in order to obtain a composite configuration that has better hole quality.

The results of this study are expected to make a scientific contribution in the form of a deeper understanding of the mechanism of delamination formation in thermoplastic composites reinforced with banana stem fibers and enrich the development of Taguchi and ANOVA-based grading process optimization methods. From a practical perspective, the results of the research can be a reference in determining optimal gurdiation parameters to improve the quality of holes, extend the service life of components, and support the development of more sustainable natural fiber-based composite materials.

II. METHODS

The method of measuring the delamination value is measured and carried out on the workbench a few moments after the machining is completed, with the intention that the workpiece is more stable. The laminated measurement was carried out using a 1600x USB microscopr, then delamination was measured by measuring the diameter of the hole produced by the gurdi (D) and the diameter of the delamination (Dmax) resulting from the gurdging process (Figure 3.6). Meanwhile, the measurement results were obtained by measuring 10 points around the hole and the delamination area formed. Then the average value is taken based on the equation, where Dmax (in mm) is the measure of the diameter due to delamination and D (in mm) is the size of the diameter of the hole produced by the grading process. Measurements are made to measure the maximum diameter length in the observed delamination area by the nominal hole diameter. After that, the delamination factor calculation is carried out using equations.

$$F_d = \frac{D_{max}}{D_{nom}}$$

Description:

F_d = factor delaminasi

D_{max} = Maximum diameter of delamination

D_{nom} = diameter lubang nominal

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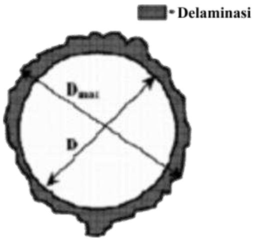


Image. 1. Delamination measurement scheme on composites

Research Design

In this study, a design was selected with an orthogonal array arrangement of the Taguchi Design with a static method. This method was chosen because of its ability in reducing the number of experiments and demonstrating possible interactions. In the selection of an orthogonal arrangement depends on the number of factors or parameters observed and the number of levels or levels of each factor.

Furthermore, based on 5 factors observed with 3 levels for each factor, the orthogonal arrangement of L27 was chosen. The factors and levels are shown in Table 3.1

Tabel 3. 1 Tabel Parameter yang digunakan

Parameter	Level 1	Level 2	Level 3
Diameter Tool (mm)	2 mm	4 mm	6 mm
Gerak Makan	0,05 Mm/rev	0,10 Mm/rev	0,15 Mm/rev
Sudut Ujung ($2k_r{}^{\circ}$)	90°	118°	135°
Serat Batang Pisang	Tegak Lurus	45°	Acak
Pendingin	Udara	Collant	Minyak Goreng

Based on the calculation results in Table 3.2, the selection of an orthogonal array design for this experimental design was obtained, so that the orthogonal matrix used is L27(3^{5}). An orthogonal matrix of type L27(3^{5}) has 5 columns and 27 rows that can be used for three independent variables, each of which has 3 levels. The experimental design for this study can be seen at Table 3.3. Next:

Tabel 3. 2 Orthogonal Array L27 ({3}^{5})

No	**Parameter**						
	Diameter Tool (mm)	**Gerak Makan (mm/rev)**	**Sudut Ujung ($2k_r$°)**	**Susuan Serat**	**Pendingin**	**Hasil Masuk (mm)**	**Hasil Keluar (mm)**
1	2 mm	0,05	90°	Tegak lurus	Udara		
2	2 mm	0,05	90°	Tegak lurus	Collant		
3	2 mm	0,05	90°	Tegak lurus	Minyak Goreng		
4	4 mm	0,10	118°	45	Udara		
5	4 mm	0,10	118°	45	Collant		
6	4 mm	0,10	118°	45	Minyak Goreng		
7	6 mm	0,15	135°	Acak	Udara		
8	6 mm	0,15	135°	Acak	Collant		
9	6 mm	0,15	135°	Acak	Minyak Goreng		
10	4 mm	0,05	118°	Acak	Udara		
11	4 mm	0,05	118°	Acak	Collant		
12	4 mm	0,05	118°	Acak	Minyak Goreng		
13	6 mm	0,10	135°	Tegak lurus	Udara		
14	6 mm	0,10	135°	Tegak lurus	Collant		
15	6 mm	0,10	135°	Tegak lurus	Minyak Goreng		
16	2 mm	0,15	90°	45	Udara		
17	2 mm	0,15	90°	45	Collant		
18	2 mm	0,15	90°	45	Minyak Goreng		
19	6 mm	0,05	135°	45	Udara		
20	6 mm	0,05	135°	45	Collant		
21	6 mm	0,05	135°	45	Minyak Goreng		
22	2 mm	0,10	90°	Acak	Udara		
23	2 mm	0,10	90°	Acak	Collant		
24	2 mm	0,10	90°	Acak	Minyak Goreng		
25	4 mm	0,15	118°	Tegak lurus	Udara		
26	4 mm	0,15	118°	Tegak lurus	Collant		
27	4 mm	0,15	118°	Tegak lurus	Minyak Goreng		

Data analysis

In this process, to see the results of the drilling machinery, a 1600x USB microscope is used which functions to see the size and thickness of the delamination formed. The data from these results will be analyzed using the taguchi method using SNR (signal to noise ratio) and ANOVA. SNR (signal to noise ratio) is used to select parameter criteria that can minimize the condition of "error variances" caused by factors that cannot be controlled using the Minitab 22 program.

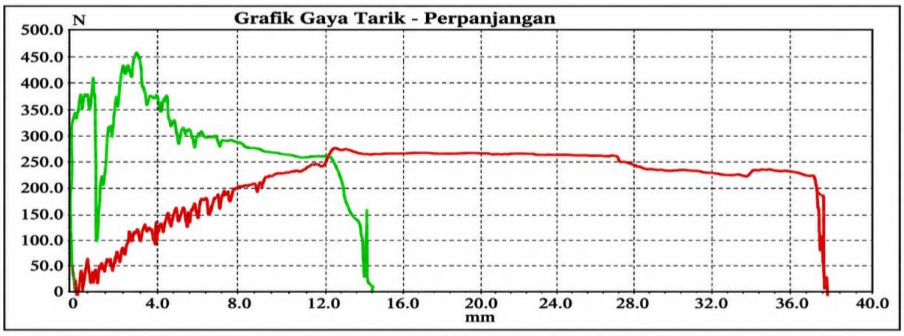
Tabel 3. 3 Format ANOVA

NO	Source	Df	Adj SS	Adjn MS	F-value	P-valve
1	Rpm					
2	Gerak Makan					
3	Pendingin					
4	Susunan serat					
5	Diameter Tool (mm)					
6	Eror					
7	Total					

III. RESULT AND DISCUSSION

Mechanical Strength of Banana Stem Fiber Composite

The use of fibers in composite materials aims to increase their strength, especially for polymer-based composite materials that have relatively low tensile strength. With the use of banana stem fiber as a reinforcer in the composite material used in this study, it is hoped that its tensile strength can be increased. The tensile test results (Figure 4.1) conducted proved that the tensile strength of composite materials reinforced with banana stem fibers increased by 61.7% of the strength of thermoplastic polymers. With the increase in tensile strength, it will have an impact on the increase in shear strength which is an indicator in determining the forces acting on the machining process. This is due to the increase in tensile strength proportional to the increase in shear strength.



Material	Max Load (N)	Yield Point (N)	Yield Strenght (N/mm²)	Tensile Strength (N/mm²)
Termoplastik murni	280.78	154.86	9.31	17.55
Termopalstik dengan penguat serat batang pisang	454.05	337.87	21.23	28.38

Image. 2. Comparison of tensile strength between pure thermoplastic polymer and reinforced with banana stem fiber

Effect of Banana Stem Fiber Composition on the Formation of Delamination Entrance

The effect of strengthening composite materials on the quality of the holes produced has been observed. The results of measuring the diameter of holes that have a build-up of material (Delamination) divided by the diameter of the resulting hole (Delamination Ratio) are noted in the following table 4.1.

Tabel. 1. Orthogonal Array L27 ({3}^{5})

No	Parameter					
	Diameter Tool (mm)	**Gerak Makan (mm/rev)**	**Sudut Ujung ($2k_r$°)**	**Susuan Serat**	**Pendingin**	**Hasil Masuk (mm)**
1	2 mm	0,05	90°	Tegak lurus	Udara	0.700
2	2 mm	0,05	90°	Tegak lurus	Collant	0,760
3	2 mm	0,05	90°	Tegak lurus	Minyak Goreng	0,670
4	2 mm	0,10	118°	45	Udara	0,800
5	2 mm	0,10	118°	45	Collant	0,640
6	2 mm	0,10	118°	45	Minyak Goreng	0.810
7	2 mm	0,15	135°	Acak	Udara	1,000
8	2 mm	0,15	135°	Acak	Collant	0,750
9	2 mm	0,15	135°	Acak	Minyak Goreng	0,970
10	4 mm	0,05	118°	Acak	Udara	0,930
11	4 mm	0,05	118°	Acak	Collant	0,890
12	4 mm	0,05	118°	Acak	Minyak Goreng	0,860
13	4 mm	0,10	135°	Tegak lurus	Udara	1,130
14	4 mm	0,10	135°	Tegak lurus	Collant	0,850
15	4 mm	0,10	135°	Tegak lurus	Minyak Goreng	0,820
16	4 mm	0,15	90°	45	Udara	0,900
17	4 mm	0,15	90°	45	Collant	0,970

18	4 mm	0,15	90°	45	Minyak Goreng	0,770
19	6 mm	0,05	135°	45	Udara	0,990
20	6 mm	0,05	135°	45	Collant	0,690
21	6 mm	0,05	135°	45	Minyak Goreng	0,650
22	6 mm	0,10	90°	Acak	Udara	1,010
23	6 mm	0,10	90°	Acak	Collant	0,970
24	6 mm	0,10	90°	Acak	Minyak Goreng	0,940
25	6 mm	0,15	118°	Tegak lurus	Udara	1,150
26	6 mm	0,15	118°	Tegak lurus	Collant	0,840
27	6 mm	0,15	118°	Tegak lurus	Minyak Goreng	0,950

. Based on the data in Table 4.1, the delamination value on the inlet side ranges from 0.640 mm to 1,150 mm. The smallest delamination value was obtained in the 5th experiment (green color), which was 0.640 mm, with a combination of 2 mm tool diameter parameters, 0.15 mm/rev feeding motion, 180° tool tip angle, 45° fiber arrangement, and adhesive coolant. Meanwhile, the highest delamination is 1,150 (red color) with a combination of 6mm tool diameter gauges, 115° mm/rev feeding motion, 118° tool tip angle, perpendicular fiber arrangement, and air cooling.

The interesting thing among the contrasting results as described above is that the ratio of low and high delamination occurs at the same end angle, which is 118°. While other cutting conditions have different values. This condition indicates that the tip angle has no significant influence on this test. This is supported by the results of the Signal-to-Noise Ratio (S/N Ratios) analysis shown in Figure 4.2. The influence of the tip angle factor only gives a curve slope of 0.272. The slope of the curve is the smallest among all the observed factors/parameters.

Furthermore, based on the results of the analysis of S/N ratios (Figure 4.1), the ones that give a large slope of the influence curve in succession are the tool diameter, feeding motion, cooler and fiber arrangement. However, based on the results of the statistical analysis of the Analisys of Variances (ANOVA) (Table 4.2), only the diameter of the tool and the type of coolant had a significant influence on the high/low value of the delamination ratio. This is indicated by the P-value that is lower than the P-value set for 95% of the confidence level (Confidence Factor), which is $P \leq 0.05$.

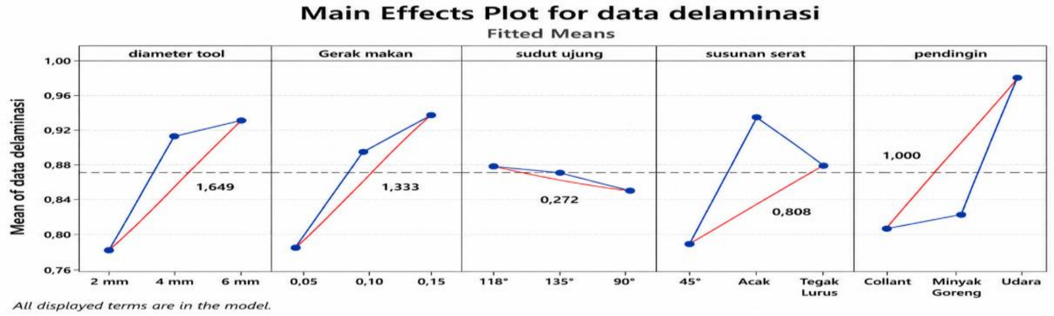


Fig. 3. The results of the analysis of S/N ratios from the influence of parameters on the ratio value Delamination on the inlet side of the hole

The cause of the diameter of the chisel and the type of coolant that has a significant influence on this study is due to the significant difference in variation between the diameter of the 2mm and 4mm chisel and between the cooking oil type coolant and the synthetic type of coolant. The variation of the levels of these two parameters causes them to have a significant influence on this study as shown from the graphical display of the results of the analysis using the ANOVA method (Figure 4.3).

Tabel. 2. Analysis Of Variance ANOVA untuk pengaruh parameter terhadap rasio delaminasi pada sisi masuk lubang (Entrance)

NO	Source	Df	Adj SS	Adjn MS	F-value	P-valve
1	Diameter Tool (mm	2	0,082719	0,041359	4,32	0,032
2	Feed Raet	2	0,079385	0,039693	4,14	0,036
3	Sudut Ujung	2	0,002163	0,001081	0,11	0,894
4	Susunan serat	2	0,067963	0,033981	3,55	0,053

5	Pendingin	2	0,108807	0,054404	5,68	0,014
6	Eror	18	0,153326	0,009583	–	–
7	Total	26	0,494363	–	–	–

Meanwhile, the variation in levels from the tip angle and fiber arrangement did not have a significant effect on the delamination ratio in this study. This is shown by the short residual distance between the levels for the three parameters mentioned above. With a difference in residual distance that is not too large it causes variations in the angle of the tip and the arrangement of the fibers cannot significantly affect the value of the delamination ratio. Although it has a relatively large curve slope (Figure 4.20), it indicates that variations in the value of the tip angle and the arrangement of the fibers will cause a change in the value of the delamination ratio.

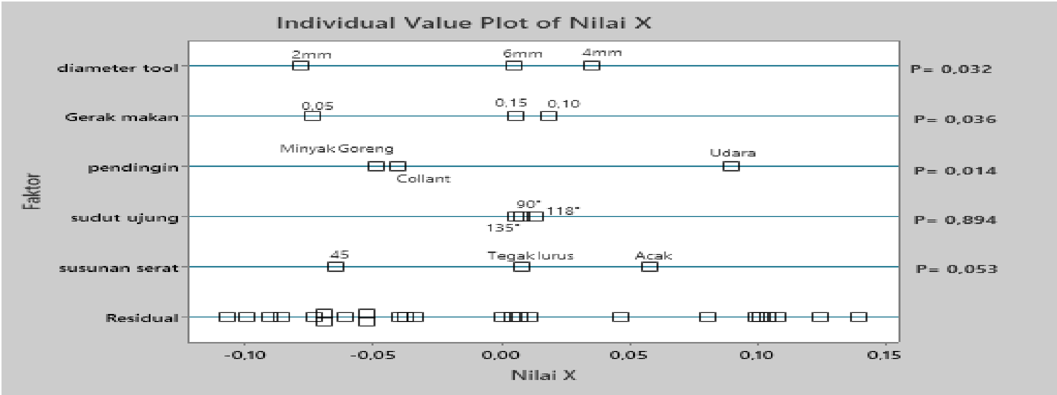


Fig. 4. Results of graph analysis from the ANOVA method

However, especially for the angle parameter of the chisel tip, although it has a P-value of 0.0597 which is slightly greater than the significance level ($\alpha = 0.05$), this parameter still has a tendency to influence the formation of delamination on the inlet side. This indicates that changes in the angle of the tool tip affect the cutting mechanism of the composite material. The increasing angle of the tip causes the area of contact between the drill bit and the workpiece to increase, so that the compressive force received by the composite surface also increases. This condition can increase the likelihood of fiber peeling around the hole, although based on the results of statistical tests the effect cannot be stated significantly.

These results are in line with the research of Heisela and Pfeifroth (2012) which states that point angle affects the quality of the drilled hole and the value of the delamination ratio in composite materials. However, the study did not conduct statistical testing so it could not be ascertained the significance of the effect of the tip angle on delamination. Therefore, the results of this study provide additional information that changes in the angle of the end indicate a tendency to affect the delamination of the inlet side, although statistically not significant.

Meanwhile, the parameters of the composition of banana stem fibers showed a P-value greater than 0.05, so statistically it did not have a statistically significant effect on delamination on the inlet side. This condition indicates that at the beginning of the drilling process, the composite layer still receives support from the layer below it so that the orientation of the fibers has not made a dominant contribution to the formation of delamination. In other words, the peel-up mechanism of delamination on the inlet side is more influenced by the magnitude of the compressive force generated by the cutting parameters than by the variation in fiber arrangement.

This phenomenon is in accordance with the research of Bambang Dwi Haripriadi and Ismet Hari Mulyadi (2018) who explained that the influence of variations in fiber composition on delamination is more dominant on the exit side than on the entrance side. This is because the inlet side of the composite layer still has a support so that the damage that occurs is relatively smaller, while the outward side of the last layer no longer has a support so that it is easier to experience delamination due to the push force of the drill bit.

Based on these results, it can be concluded that in inlet side delamination, the diameter of the tool is the most influential parameter, while the tip angle has a tendency to affect delamination but is not statistically significant, and the fiber arrangement has not shown a significant influence. Therefore, in order to obtain a better quality of the hole on the inlet side, the selection of the appropriate tool diameter is the main factor that needs to be considered in the process of drilling the fiber fiber of the banana stem.

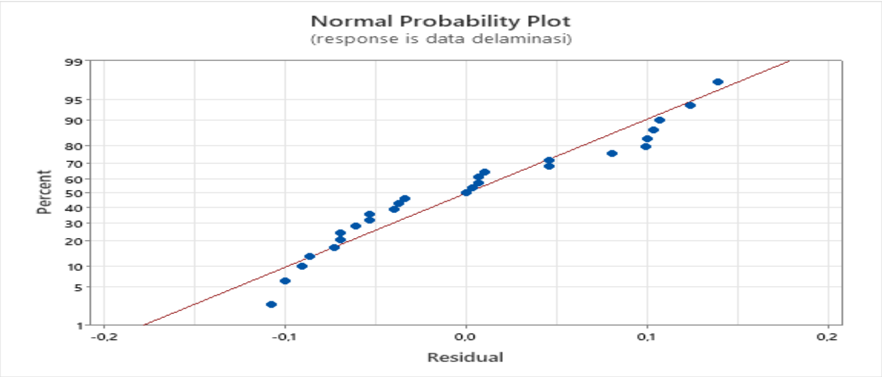


Fig. 5. The result of data normality to the redisual value

This condition occurs possibly due to parallax error. Parallax error occurs due to different viewpoints when measuring the delamination ratio of images taken using a microscope. This causes the measurement line size not to reflect the actual value. This analysis is also supported by the results of the Normal Probability Plot as shown in Figure 4.20. There are only three residual points that are outside the approach line (straight line). However, overall the data can be said to be distributed normally, so the results of this study can be said to be relatively valid to draw conclusions.

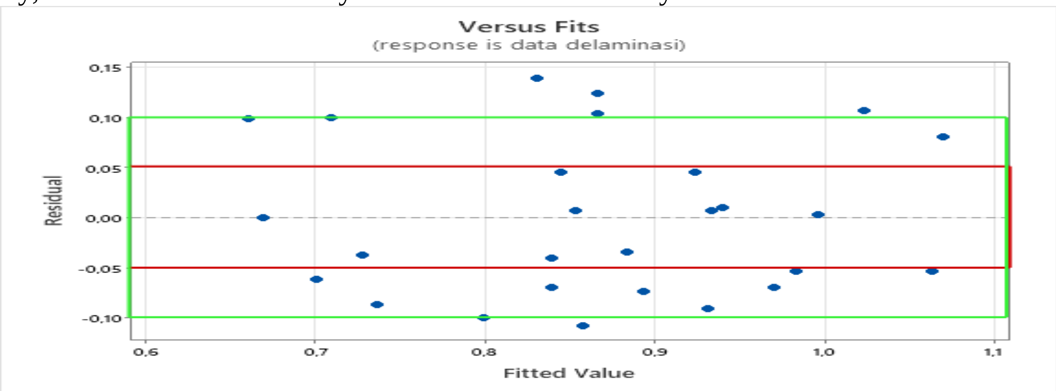


Fig. 6. Distribution of delamination to residual value values for each combination of parameters observed inlet

It is seen that the residual points are randomly scattered above and below the zero line without forming a specific pattern, such as a curved pattern or a funnel pattern. Most of the points are in the residual range of around -0.10 to 0.14, with a relatively even spread along the predicted value of 0.65–1.08. There are no extreme deviation points or groupings in one particular area. This shows that residual variance is constant (homoskedasticity) and there is no systematic relationship between the residual and the predicted value. Thus, the ANOVA model has fulfilled the assumption of similarity of variance so that the results of the delamination analysis on the entry side can be declared valid and reliable.

Exit

As is the case with the entrance of the hole, observation of the formation of delamination is also carried out at the exit of the hole (Exit). The results of the observation that delamination is formed due to the influence of several cutting parameters and fiber arrangement are shown in Table 4.3. From Table 4.3, it can be seen that moderate diameter (6mm), small feeding motion (0.10 mm/r), moderate chisel tip angle (90o), random fiber arrangement and cooking oil coolant provide the possibility of small delamination in the hole outlet. Meanwhile, the large delamination ratio is caused by the selection of the tool diameter (4mm), moderate feeding motion (0.10 mm/r), moderate tool tip angle (135o), and the use of collant as a tool cooling medium and fiber arrangement with a perpendicular orientation.

Tabel 4. 3 Orthogonal Array L27 ({3}^{5})

No	Parameter

	Diameter Tool (mm)	Gerak Makan (mm/rev)	Sudut Ujung ($2k_r$°)	Susuan Serat	Pendingin	Hasil Keluar (mm)
1	2 mm	0,05	90°	Tegak lurus	Udara	0,770
2	2 mm	0,05	90°	Tegak lurus	Collant	0,640
3	2 mm	0,05	90°	Tegak lurus	Minyak Goreng	0,730
4	2 mm	0,10	118°	45	Udara	0,690
5	2 mm	0,10	118°	45	Collant	0,680
6	2 mm	0,10	118°	45	Minyak Goreng	0,670
7	2 mm	0,15	135°	Acak	Udara	0,860
8	2 mm	0,15	135°	Acak	Collant	0,880
9	2 mm	0,15	135°	Acak	Minyak Goreng	0,970
10	4 mm	0,05	118°	Acak	Udara	0,920
11	4 mm	0,05	118°	Acak	Collant	0,880
12	4 mm	0,05	118°	Acak	Minyak Goreng	0,900
13	4 mm	0,10	135°	Tegak lurus	Udara	1,040
14	4 mm	0,10	135°	Tegak lurus	Collant	1,150
15	4 mm	0,10	135°	Tegak lurus	Minyak Goreng	1,010
16	4 mm	0,15	90°	45	Udara	1,060
17	4 mm	0,15	90°	45	Collant	0,690
18	4 mm	0,15	90°	45	Minyak Goreng	1,000
19	6 mm	0,05	135°	45	Udara	1,030
20	6 mm	0,05	135°	45	Collant	0,880
21	6 mm	0,05	135°	45	Minyak Goreng	0,730
22	6 mm	0,10	90°	Acak	Udara	0,710
23	6 mm	0,10	90°	Acak	Collant	0,620
24	6 mm	0,10	90°	Acak	Minyak Goreng	0,590
25	6 mm	0,15	118°	Tegak lurus	Udara	1,380
26	6 mm	0,15	118°	Tegak lurus	Collant	0,890
27	6 mm	0,15	118°	Tegak lurus	Minyak Goreng	0,890

Furthermore, the formation of delamination with both low and high ratios on the exit side of the hole is influenced by the same cutting parameters, namely feed rate with a moderate value (0.10). This illustrates that a feed rate with a moderate value will not cause a change in the value of the delamination ratio.

However, based on the results of the analysis of Signal-to-Noise Ratios with the smaller is the better approach as shown in Figure 4.21, the feed rate provides a curve slope with the third-rank ranking value. Which, despite being under the arrangement of fibers and cooling media, statistically; through the Analysis of Variances (ANOVA) as shown in Table 4.4, feed rate has a significant influence. This is because the P-value is lower than that set at the 95% confidence level, which is around

1.1. While the one with the first rank is the end angle.

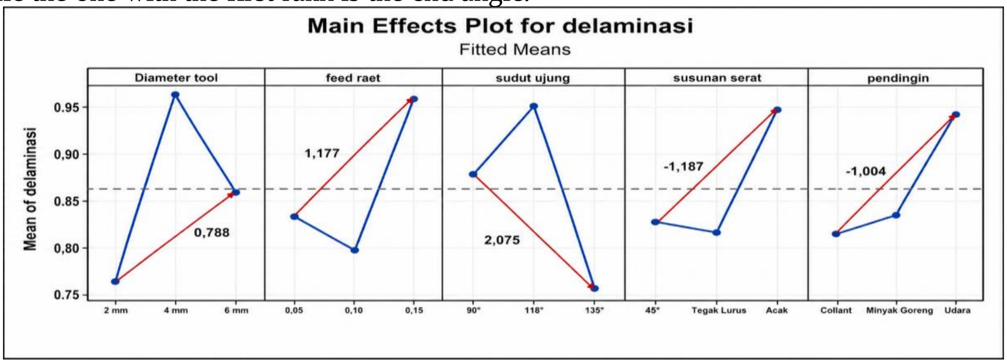


Fig. 7 The results of the analysis of S/N ratios from the influence of parameters on the ratio value

Delamination on the exit side of the hole

In the observation of the formation of delamination on the exit side of the hole, it is indicated that only a slight coolant does not affect the high and low value of the delamination ratio in the process of drilling the hole in composite material with a banana stem reinforcement. Meanwhile, statistically, the P-value for the fiber arrangement has passed the set P-value of 0.05 with a confidence level of 95%.

Table 4.4 Analysis Of Variance ANOVA for the effect of parameters on the delami-rice ratio on the Exit side

NO	Source	Df	Adj SS	Adjn MS	F-value	P-valve
1	Diameter Tool (mm)	2	0,17227	0,08614	5,88	0,012
2	Feed Raet	2	0,13087	0,06544	4,47	0,129
	Sudut Ujung	2	0,17179	0,08589	5,87	0,012
3	Susunan serat	2	0,09347	0,04674	3,19	0,068
4	Pendingin	2	0,08503	0,04251	2,90	0,084
5	Eror	18	0,23430	0,01464	–	–
6	Total	26	0,88774	–	–	–

If you refer to the ANOVA graph in Figure 4.7, this is likely due to the strength between the random fiber array and the fiber array with almost the same orientation of 45o. As a result, the selection of both types of fiber arrays will reduce the effect it has on the response. In addition, if we pay attention to the combination of parameters that affect the value of high and low delamination ratios in Table 4.4, these two types of fiber arrays have contributed to producing high and low delamination ratio values.

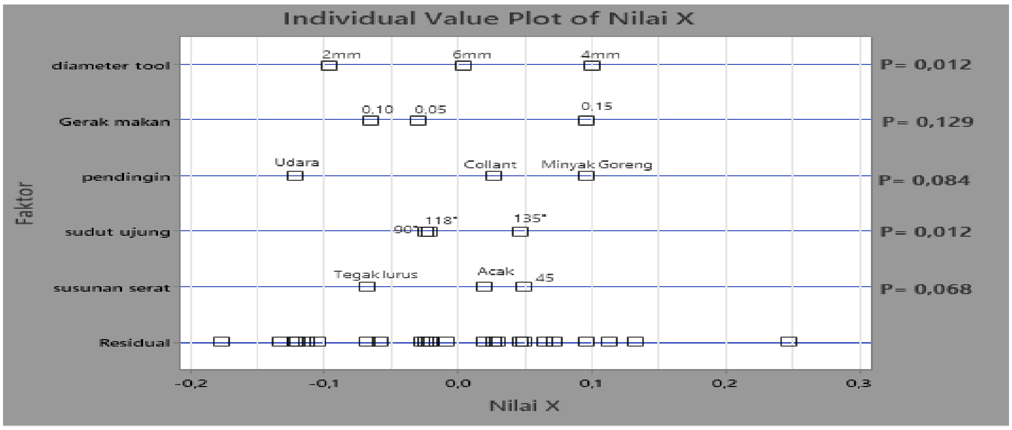


Fig. 8. Results of graph analysis from the ANOVA metho

However, especially in the parameter of the fiber arrangement of banana stems, although it has a P-value of 0.068 which is slightly greater than the significance level (α = 0.05), this parameter still shows a tendency to influence the formation of delamination on the outward side. This suggests that changes in fiber orientation affect the composite's ability to withstand the thrust that occurs when the drill bit exits the material. Fiber arrangements that have better interfiber bonds will be able to distribute the load more evenly so that layer separation can be minimized. In contrast, a less dense or random arrangement of fibers tends to result in greater delamination values.

These results are in line with the research of Bambang Dwi Haripriadi and Ismet Hari Mulyadi (2018) who stated that variations in fiber composition have a more pronounced influence on the formation of delamination on the exit side than on the entrance side. This condition occurs because by the time the drill bit is about to penetrate the material, the last layer of the composite no longer obtains a support so that the entire thrust force is received by the layer. As a result, the ability of fibers to maintain bonds with the matrix is an important factor that determines the amount of delamination formed.

In addition to the fiber arrangement, the angle parameters of the tool tip also show a tendency to affect delamination on the outward side. Changes in the angle of the tool tip cause changes in the cutting mechanism and force distribution during the drilling process. An angle of the tip that is too large will increase the thrust received by the last layer of the composite so that the tendency of push-out delamination is higher. However, based on the results of ANOVA, pengaruh tersebut belum dapat dinyatakan statistically significant because the P-value is still above the level of significance used.

In general, delamination on the exit side has a greater degree of damage than delamination on the inlet side. This is because on the outside side of the composite layer no longer gets support from the material underneath so that it is easier to crack and detach due to the push force of the drill bit. This condition causes machining parameters such as chisel diameter, feeding motion, chisel tip angle, cooling media, and fiber arrangement to have a greater influence on the quality of the hole on the outside side.

Based on the results of this study, it can be concluded that the diameter of the tool is the most influential parameter on the delamination of the outer side, while the arrangement of the fibers shows a tendency to affect delamination although it is not statistically significant. Therefore, to obtain a better hole quality in banana stem fiber composites, the selection of appropriate tool diameters and the use of fiber arrangements that are able to increase the bond strength between layers are important factors in minimizing the formation of delamination on the outer side.

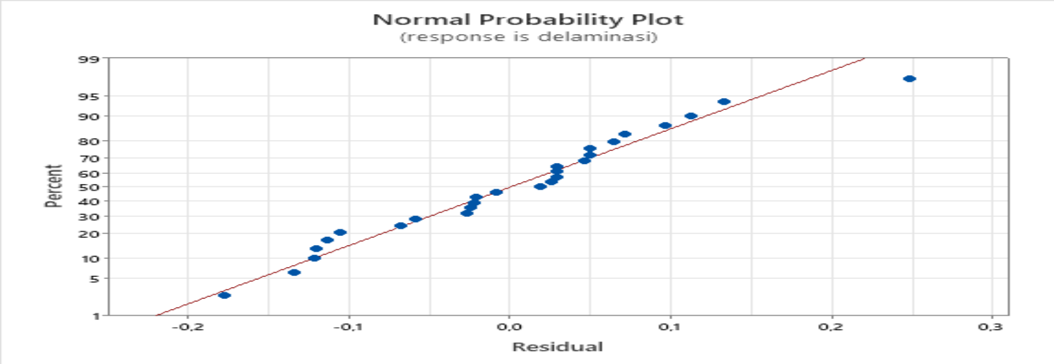


Fig. 9. The result of data normality to the redisual value

This condition occurs possibly due to parallax error. Parallax error occurs due to different viewpoints when measuring the delamination ratio of images taken using a microscope. This causes the measurement line size not to reflect the actual value. This analysis is also supported by the results of the Normal Probability Plot as shown in Figure 4.20. Where there is only one residual point that is outside the approach line (straight line). However, overall the data can be said to be distributed normally, so the results of this study can be said to be relatively valid to draw conclusions.

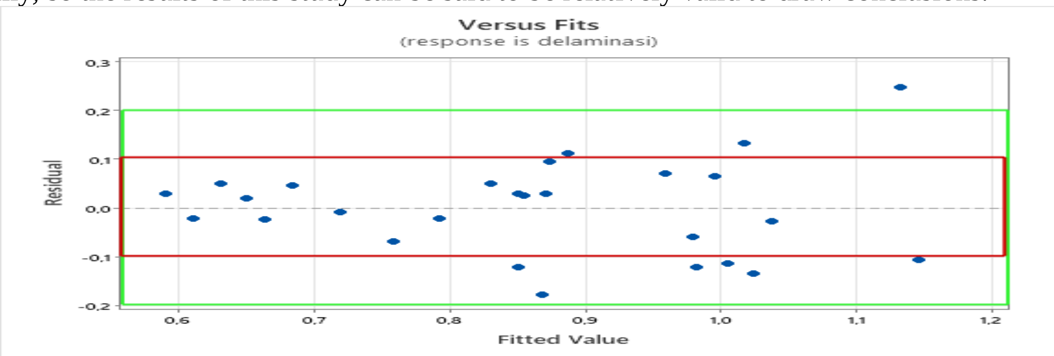


Fig. 10. Distribution of delamination to residual value values for each combination of parameters observed by the exit hole (Exit)

It is seen that the residual points are randomly scattered above and below the zero line without forming a specific pattern, so it does not show a systematic relationship between the residual and the predicted value. Most of the points are in the residual range of -0.18 to 0.14, while there is one point with a residual of about 0.25 which is higher than the other points. However, these points still do not form a pattern that affects the overall residual spread. This shows that the residual variance is constant (homoskedasticity) and that the ANOVA assumption has been met. Thus, the statistical model used to analyze delamination on the exit side is valid and trustworthy.

IV. CONCLUSION

Based on the results of research and analysis using the Taguchi and ANOVA methods on the process of drilling the banana stem fiber composite, several conclusions can be drawn as follows.

The results of the analysis showed that the parameters of the drilling process had an effect on the formation of delamination in the fiber composite of banana stems. Of all the parameters tested, the diameter of the tool was the most dominant parameter affecting delamination, both on the entrance and exit sides. The larger the diameter of the tool used, the greater the cutting force and thrust force that occurs, so the value of the delamination factor tends to increase.

In entrance delamination, damage occurs due to the peel-up delamination mechanism, which is the exfoliation of the surface layer when the drill bit begins to enter the material. Based on the results of ANOVA, the diameter of the tool has a significant influence, while the angle parameter shows a tendency to influence even though it is not statistically significant. Variations in fiber composition have not had a significant effect on inlet side delamination.

In exit delamination, damage occurs due to the push-out delamination mechanism, which is pushed into the last layer of composite when the drill bit penetrates the material. The delamination value on the exit side is generally greater than on the inlet side because the last layer no longer has a buffer. The results of the analysis showed that the diameter of the tool remained the most influential factor, while the arrangement of the fibers showed a tendency to affect delamination although it was not statistically significant.

The analysis using the Taguchi method with the Smaller The Better criterion was able to determine a combination of process parameters that resulted in a lower delamination value. The Taguchi method combined with ANOVA is effectively used to evaluate the influence of each process parameter on the quality of the drilled holes in banana stem fiber composites.

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