The effect of machine process in two flute endmill feeding rate on delamination in carbon fiber reinforced polymer materials

Cite as: AIP Conference Proceedings **2384**, 040003 (2021); https://doi.org/10.1063/5.0077563
Published Online: 30 December 2021

Formanto Paliling, Ahmad Yusran Aminy and Hairul Arsyad

The Effect of Machine Process in Two Flute Endmill Feeding Rate on Delamination in Carbon Fiber Reinforced Polymer Materials

Formanto Paliling[a)], Ahmad Yusran Aminy[b)] and Hairul Arsyad[c)]

Department of Mechanical Engineering, Faculty of Engineering, Universitas Hasanuddin Gowa, Indonesia 92171

a) Corresponding author: fpaliling@gmail.com
b) ahmadyusrana@yahoo.co.id
c)arsyadhairul@yahoo.com

Abstract - Currently Carbon Fiber Reinforced Polymer (CFRP) is widely used in the aircraft and automotive industries, due to its superior mechanical properties such as lightweight, high resistance properties which are very good for corrosion resistance. The aircraft and automotive components made of CFRP composites have their constraints, namely the phenomenon of delamination when the composite material is drilled. To analyze this delamination phenomenon, it is necessary to investigate the effect of the feed rate of the two flute end mill on the delamination of the material holes. The experiments carried out included variations in the feed rate of the end mill tool in each hole. The output of this study is a statistical percentage of how the effect of the end mill tool feed rate on delamination defects. The results of the test analysis can provide information on how the feed rate of the end mill affects delamination.

INTRODUCTON

Currently, Carbon Fiber Reinforced Polymer (CFRP) is a material that is most widely because of its mechanical properties. The use of carbon fiber as a reinforcement for this composite material has emerged and has begun to develop. The choice of Carbon Fiber Reinforced Polymer (CFRP) material for industrial use occurs because of its high strength ratio and can be formed easily and at a relatively affordable cost. Because of the favorable properties mentioned above, this material is the most dominant material to replace conventional metals in general [1]. So, the objective of this research is to analyze how the feed rate affects the quality of delamination produced by drilling the CFRP material.

The properties of Carbon Fiber Reinforced Polymer (CFRP) composite materials including high strength, lighter weight, high-temperature tolerance, corrosion resistance, and low coefficient of thermal expansion make it the most attractive material currently for aircraft structures. Airplanes are complex machines consisting of thousands of components. Joining these components together requires thousands of rivet or bolt holes. Therefore, the process of making boreholes is a necessary machining process in the aerospace industry [2]. As a result of the increasing use of CFRP in the aerospace industry, CFRP machining has extensively studied. The majority of these studies considered CFRP drilling, as it is the most common process of structural machining parts used in aircraft. In a study, it is showing that the drilling process parameters and drill geometry could affect the whole quality of the CFRP material [3].

Drilling is one of the most frequently applied processes for CFRP machining [4]. In the drilling of CFRP materials, the most common defect of CFRP material holes is delamination, which can be evaluated by a delamination factor [5]. Abnormalities associated with drilling for Carbon Reinforced Polymers (CFRP), for example, delamination, which is a significant problem for industries, including the automotive and aerospace industries [6].

The 4th International Conference on Materials and Metallurgical Engineering and Technology (ICOMMET) 2020
AIP Conf. Proc. 2384, 040003-1–040003-12; https://doi.org/10.1063/5.0077563
Published by AIP Publishing. 978-0-7354-4174-3/$30.00

Drilling research intended to show the characteristic value of delamination defects that occur during the drilling process [7]. The spread of delamination is often demonstrated by milling in CFRP specimens, which have different fiber orientations. Therefore, in analyzing the effect of drilling variables on delamination, a machining variable is needed to observe the hole quality of the CFRP material [8].

However, drill geometry is an essential factor that determines the drill hole quality. In borehole, the rate determined some parameters, such as fiber direction and delamination [9]. From there, it can understand that the effect of process parameters such as cutting and accuracy of the shape of the drilled hole and cutting strength influenced by the geometry of the drill itself [10].

In the assembly of machine construction, parts made of composite materials are often with the type of bolt connection. Therefore, drilling is one of the most common machining operations. However, this process causes various kinds of damage, such as delamination [11]. it is necessary to experiment with several machining variables, for example, the milling machine by varying the spindle speed and the feed rate on the CFRP material. [12].

The drilling process parameters will evaluate by combining the spindle speed and feed rate. The results of the optimization show that the feed rate is the most important thing. [13].

Drilling parameters such as cutting speed ratio, feed rate, drill type, and drill diameter, will give rise to material defects such as delamination. From this, to investigate delamination defects Isbilir, O., and Ghassemieh, E investigated the CFRP drilling process by varying the spindle speed, and feed rate, and the drill used was a tungsten carbide type that had a TiAlN / TiN layer. [14] [15].

Therefore the drilling observed in this study focuses on variations in spindle speed and feed rate adjusted according to the drill design. Furthermore, to analyze the delamination, it is also necessary to observe the exit side hole [16]. Delamination defects in CFRP materials often depend on the quality of the drilling, as well as the type of tool used [17]. In analyzing the hole quality, delamination explains where the variation of spindle speed and device feed determine by a particular kind of means [18].

RESEARCH METHODS

Machining Process

Computer Numerical Control (CNC) is one of the core components in a precision manufacturing process. Also, the existence of CNC machines has become a vital asset for manufacturing industries because these tools can produce mass products or make the necessary components with a high degree of accuracy and precision. CNC machines also have experienced very rapid development at this time. With the CNC machine, it can reduce operator intervention while the engine is operating, thus simplifying and speeding up the work of a product. The TU 3A CNC milling machine is computer-controlled so that all movements will run automatically according to the program commands given so that with the same program, the CNC machine can instruct to repeat the program execution process continuously. The working principle of the TU 3A CNC milling machine is a rotating knife, while the workpiece on the Table moves horizontally or across. See Figs. 1 and 2.

FIGURE 1. Image of T.U. CNC-3A machine.

(a) (b)

FiGURE 2. (a) endmill two flute (b) the cutting side of the endmill.

The endmill is a type of blade that looks like a drill bit but include in the milling cutter category. In machining industry technology, the endmill is also known as a cutting tool used in carving applications in milling machines and can also use for CNC machines. The advantages of some endmills can use to cut in several directions. For this research, this milling knife uses to make holes in CFRP material.

MATERIAL AND EXPERIMENTAL SET-UP

Delamination

Delamination is the stripping of the thin surface layer of the CFRP material structure. Delamination is a model of critical damage that occurs in laminated composites. Delamination occurs due to several factors such as high interlaminar stresses and stress concentrations at the crack site or other damage to the laminate. The delamination factor (Fd) has widely used in characterizing the degree of workpiece damage in the drilling inlet and outlet holes. The Fig. 3 below shows the delamination visualization scheme. The delamination factor (Fd) can calculate:

$$Fd = \frac{D_{max}}{D} \quad (1)$$

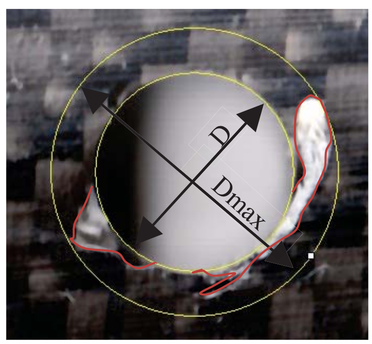


FIGURE 3. Delamination on Carbon Fiber Reinforced Polymer (CFRP).

Entry and Exit Sides Delamination

As it is known, delamination is the process of exfoliating the outer layer of the material, in this case, the CFRP material. In the drilling of CFRP material, two delamination processes occur, namely the delamination of the entry side and delamination of the exit side, so it is necessary to observe this phenomenon. One of the wonders in delamination is entry side delamination. Entry side delamination often sees that the peeling process will be lower than the exit side delamination process. Fig. 4 is one of the entry sides in the delamination process, which is commonly called entry side delamination. In observing this delamination, it is also essential to know that one of the causes is the feed rate

One of the delamination processes is the exit side delamination, as shown in Fig. 5. It shows the exit side delamination characteristics, namely a defect that occurs when the drill bit penetrates the CFRP material. From Fig. 5, we can see that the delamination of the exit side of the resulting deficiency is greater than that of the entry side.

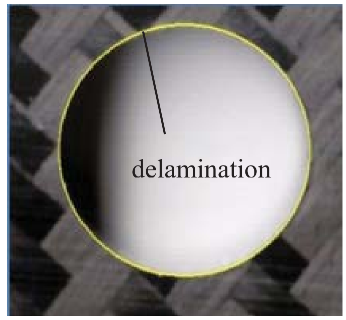


FIGURE 4. Delamination Entry Side Characteristics.

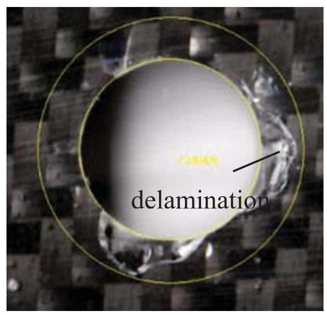
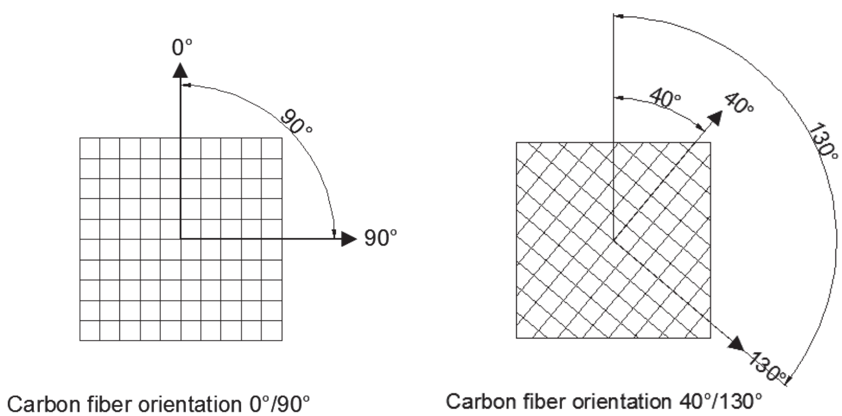


FIGURE 5. Delamination Exit Side Characteristics.

Fiber Orientation

In this study, we were using two types of fiber orientation, the first orientation (a) $0^0/90^0$ in the first layer, the second orientation of the carbon fiber with the coating (b) $40^0/130^0$, and for the third layer using fibers with (a) $0^0/90^0$, as shown in Fig. 6. The purpose of using this fiber direction expect to improve the quality of the drilling results of CFRP material.



(a) (b)

FIGURE 6. (a) Orientation direction of $0^0/90^0$ and (b) Orientation $40^0/130^0$ in CFRP material.

CFRP Material Dimensions

Fig. 7 shows an AutoCAD image of the location of the CFRP material drilling with dimensions of 120 mm x 120 mm. And also the area of the numbering corresponds to the position of the infeed rate, and at an adjustable distance between the holes of the CFRP material**.**

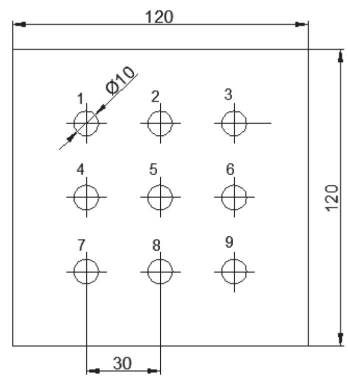


FIGURE 7. Dimensions of the CFRP specimen drilled with a diameter of 10 mm.

Data Analysis Techniques

The data analysis process is carried out after research testing, where the data obtained will be tabulated, then analyzed through ANOVA data processing based on a P-value if it is above 0.05 then the effect is not significant or only substantially but if it is below 0.05, the effect is The next significant contribution column shows the percentage value of the effect of the drilling machining parameters with a two-flute end mill blade.

RESULTS AND DISCUSSION

Description of Research Results

The results obtained from this study are data from the effect of machining testing and the consequences of calculations based on testing that can display in tables, graphs, and the results of the ANOVA method.

The machining process resulting from the milling hole carried out using the TU. Control machine. CNC-3A. This machine classifies as a CNC milling machine that is capable of milling through the drilling process so that the machining variables of this machine are more accurate than using an ordinary hand drill. So that in observing the phenomenon that occurs in the endmill drill bit that utilizes this machine, it is hoped that the results will be more accurate and useful.

The data collection variables carried out in this study are shown in Tables 1 and 2. From this table, it can see how the description of the drilling process with various feed variations followed by spindle speed so that the above variables will have a direct effect on the delamination defect process.

The delamination factor can be observed by (FD) the delamination factor. Furthermore, from the delamination defect value that has tabled, then analyzed and entered into a graph to compare how the effect occurs. ANOVA simulation performs to observe the contribution of each CFRP material. The same is done for the bottom delamination to determine the impact of the feed rate on the base delamination of the CFRP material drilling results.

These results are then summarized by the ANOVA method to determine the variables that affect the CFRP feed rate of delamination.

Measurement of Machined Hole Quality

In making measurements in research, it is necessary to measure delamination. The delamination can calculate using Eq. (1). After taking the measurements then the results of the delamination factor (FD) calculation are tabulated in Tables 1 and 2.

Entry Side Delamination Results

TABLE 1. The results of delamination tests for entry side and exit-side with an endmill diameter of 10 mm

No Hole	Spindel Speed (RPM)	Feed Rate (mm/min)	Entry Side
1	500	40	1,063
2	500	50	1,059
3	500	60	1,055
4	1000	40	1,068
5	1000	50	1,055
6	1000	60	1,046
7	2000	40	1,051
8	2000	50	1,046
9	2000	60	1,038

TABLE 2. Two-Way ANOVA Test Results on the entry side delamination

Source	DF	SS	MS	F	P	Contribution %
Feed rate	2	0,0003082	0,0001541	11,32	0,023	44,40 %
Spindle	2	0,0003316	0,0001658	12,18	0,020	47,76 %
Error	4	0,0000544	0,0000136			7,84 %
Total	8	0,0006942				

From Table 2 we can see that based on the ANOVA test using a significance of 0.05 where the P-value is less than 0.05, it shows that the effect of feed rate and spindle speed is very significant. Still, if it is seen based on the percentage contribution, the spindle speed has a greater influence in the drilling of CFRP material.

From the variation in the feed rate in Fig. 8, it shows that with a spindle rotation of 500 RPM with a variation of the feed rate of 40 mm/min, it has a substantial amount of damage. It will decrease with an increasing feed rate of 50 mm/min to 60 mm/min. Shows the effect of reducing delamination defects. Significantly as the feed rate of the CFRP material increases.

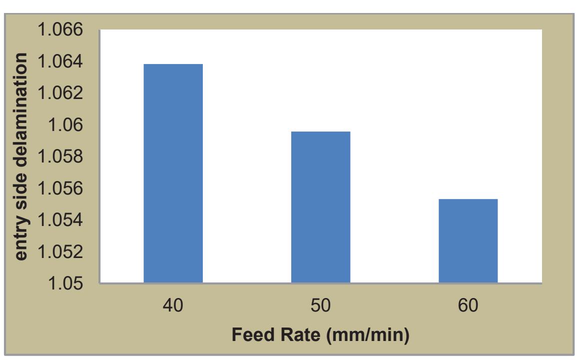


FIGURE 8. Graph of entry side delamination factor based on feed rate variation of 40, 50, 60 mm / min (N = 500 rpm).

The same thing also shows in Fig. 9. It can seem that a spindle rotation of 1000 RPM with a variation of the feed rate of 40 mm/min has a large amount of damage. Will decrease with increasing the feed rate from 50 mm/min to 60 mm / min. Shows the effect of reducing delamination defects. Significantly because of the CFRP material feed rate increases.

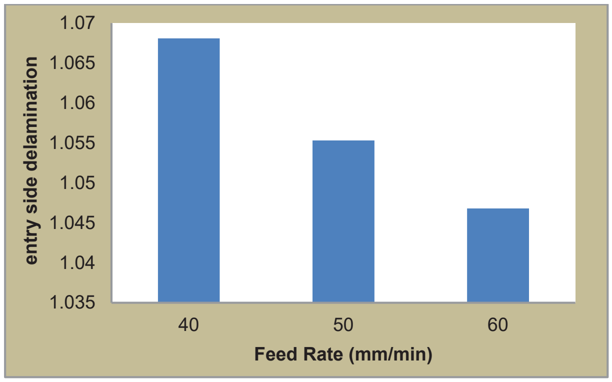


FIGURE 9. Graph of entry side delamination factor based on variation of feed rate 40, 50, 60 mm / min (N = 1000 rpm).

Fig. 10, using a 2000 RPM spindle speed, shows that at a feed rate of 40 mm/minute, there is significant damage. It decreases with the addition of a feed rate with a limit of 60 mm/minute so that the optimal conditions in this experiment show that the three parameters are 60 mm / minute.

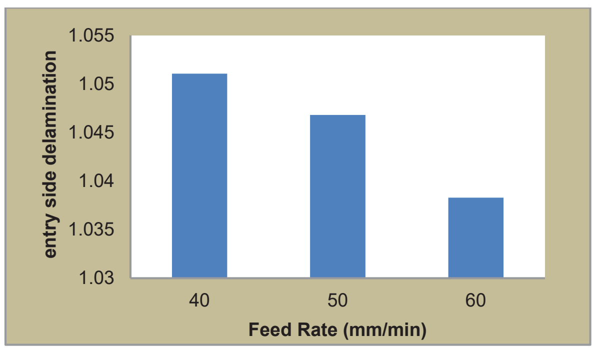


FIGURE 10. Graph of entry side delamination factor based on variation of feed rate 40, 50, 60 mm / min (N = 2000 rpm).

Fig. 11 shows the combined conditions of Fig. 8, Fig. 9, and Fig. 10. Fig. 11 shows the optimal conditions at 60 mm/min. So the effect of the feed rate from Fig. 11 shows a significant impact in this experiment. So that the entry side delamination condition shows the effects of the feed rate on the entry side delamination defect; however, it is not substantial such as the exit side delamination.

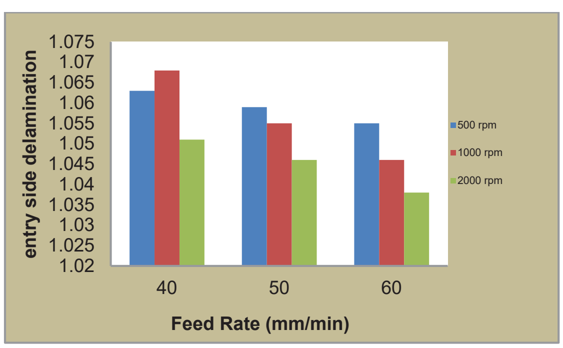


FIGURE 11. Graph of feed rate effect based on entry side delamination.

The interaction between the feed rate and the spindle speed on the delamination factor according to Fig. 12, shows the smallest parameter value shown at an feed rate of 60 mm/min and a spindle speed of 2000 RPM.

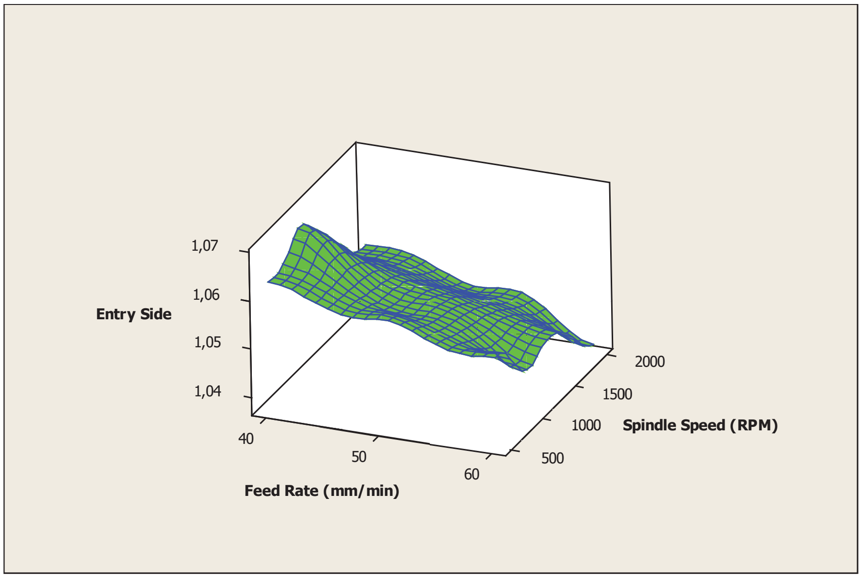


FIGURE 12. 3D Interaction between feed rate and spindle speed on entry side.

Exit Side Delamination Results

From Tables 3 and 4, we can see that based on the ANOVA test concerning the significance of less than 0.05, it can be seen that the spindle speed has a significant effect on exit side delamination damage. In contrast, the feed rate has a significance of more than 0.05, which shows a substantial effect.

TABLE 3. The results of delamination tests for entry side and exit side with an endmill diameter of 10 mm

No Hole	Spindel Speed (RPM)	Feed Rate (mm/min)	Exit Side
1	500	40	1,468
2	500	50	1,463
3	500	60	1,297
4	1000	40	1,165
5	1000	50	1,246
6	1000	60	1,072
7	2000	40	1,063
8	2000	50	1,055
9	2000	60	1,068

TABLE 4. Two-Way ANOVA Test Results on the exit side delamination

Source	DF	SS	MS	F	P	Contribution %
Feed rate	2	0,019848	0,0099241	2,77	0,176	8,70 %
Spindle	2	0,192111	0,0960554	26,79	0,005	84,90 %
Error	4	0,014340	0,0035851			6,4 %
Total	8	0,226300				

Fig. 13 shows that the spindle speed of 500 RPM shows that the feed rate variation of 40 mm/min to 50 mm / min has decreased although not significantly, and at 50 mm / min to 60 mm / min, it has reduced substantially. So that at 60 mm/min feed is the optimal condition at the feed rate. So it can be seen that the feed rate influences the process using a milling machine.

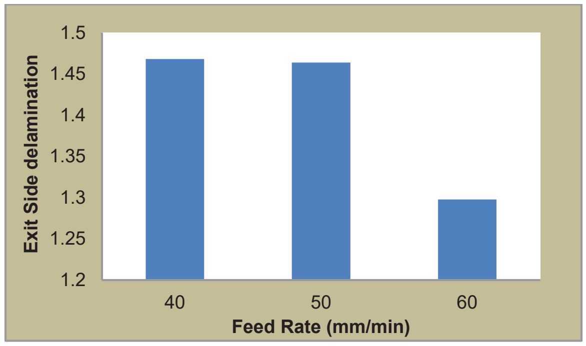


FIGURE 13. Graph of exit side delamination factor based on variation of feed rate 40, 50, 60 mm / min (N = 500 rpm).

From Fig. 14 with a rotation speed of 1000 RPM seen from the variation of the feed rate (40 mm / minute, 50 mm / minute, 60 mm / minute), it can be seen that at the feed rate from 40 mm / minute to 50 mm / minute the graph has increased, which shows the degree of delamination defect value under the hole of the material increases, shows the effect of the infeed rate value. Whereas at a feed rate of 50 mm/minute to 60 mm / minute, the graph decreases, which shows a reduction in the amount of the defect defects of the CFRP material hole delamination.

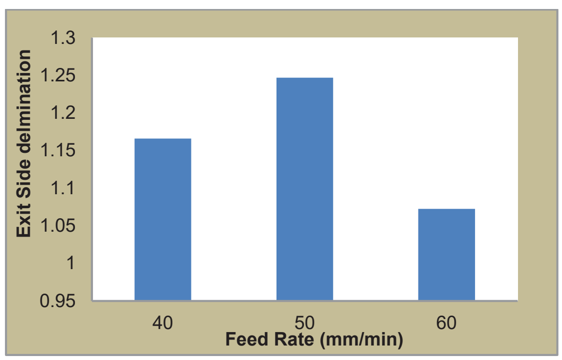


FIGURE 14. Graph of exit side delamination factor based on variation of feed rate 40, 50, 60 mm / min (N = 1000 rpm).

From Fig. 15 with a speed of 2000 RPM and a variety of feed rates (40 mm / minute, 50 mm / minute, 60 mm / minute), it can seem that at a feed rate of 40 mm / minute to 50 mm / minute the graph has decreased, which shows the defect rate of the material delamination decreases which shows the effect of the infeed rate value. Meanwhile, at a feed rate of 50 mm/minute to 60 mm / minute, the graph has increased, which shows an increase in the value of the defective defects of the CFRP material holes.

In Fig. 16, with the variation of the feed rate, the best condition rate is shown at 60 mm/min infeed. Fig. 16 indicates that the effect of the feed rate plays a role in the varied feed rates. So it can be seen that the feed rate has a significant impact on the 60 mm / min feeding conditions

The interaction between the feed rate and the spindle speed on the delamination factor according to Fig. 17, shows the smallest parameter value shown at an feed rate of 60 mm/min and a spindle speed of 2000 RPM.

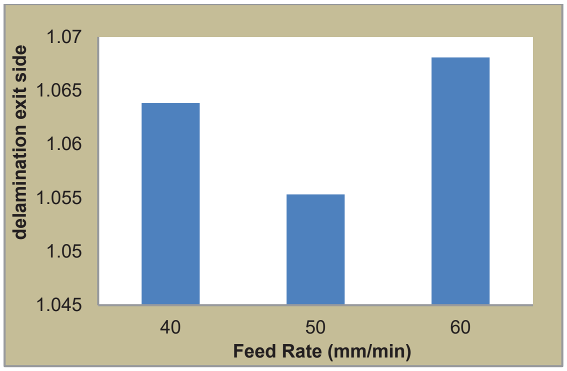


FIGURE 15. Graph of exit side delamination factor based on variation of feed rate 40, 50, 60 mm / min (N = 2000 rpm).

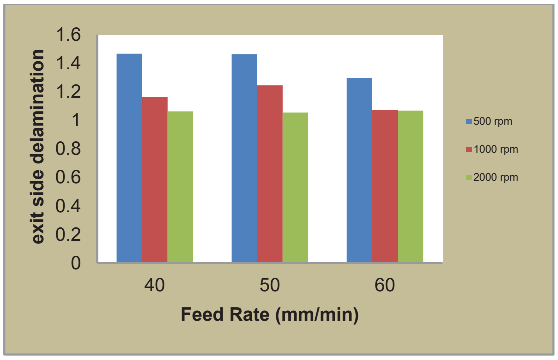


FIGURE 16. Graph of feed rate effect based on exit side delamination.

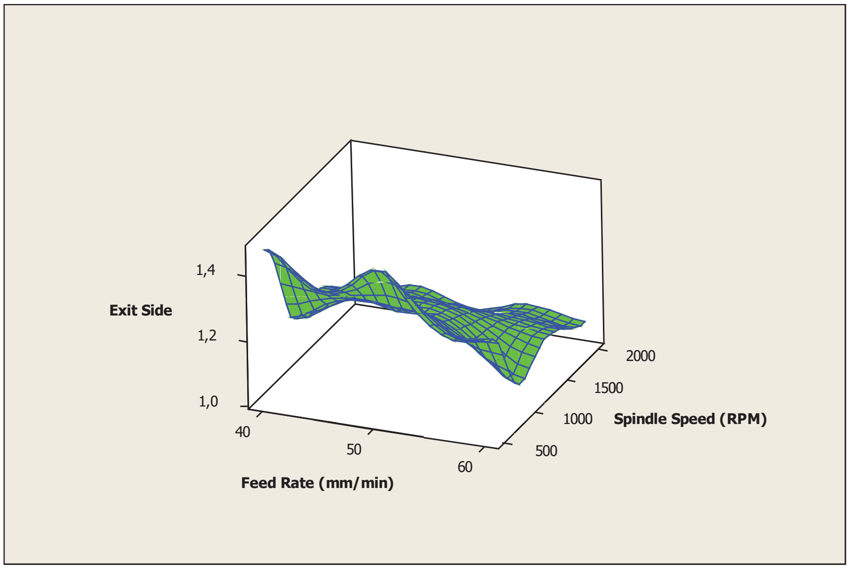


FIGURE 17. 3D Interaction between feed rate and spindle speed on exit side.

CONCLUSION

1. In general, the entry side delamination has a smaller delamination defect than the exit side. However, for the entry side delamination, the feed rate parameter and spindle speed are very significant. Conversely, on the exit side, the spindle speed has a significant effect than the feed rate, which only substantially affects this because of the feed rate decreases, spindle speed increases when the endmill blade penetrates the CFRP material.
2. The ANOVA simulation design can suggest combining machining parameters better.

ACKNOWLEDGMENTS

The authors would like to thank the support from the Politeknik Negeri Ujung Pandang and Faculty of Engineering, Hasanuddin University Makassar and the most significant appreciation for permitting to research in the laboratory for this research so that this research can be complete properly.

REFERENCES

1. Qureshi, M. A. M., Khan, S. A., Bhutta, M. M. A., Saleem, M. Q., & Harris, M. (2017). Carbon fiber-reinforced polymer composite drilling via aluminum chromium nitride-coated tools: Hole quality and tool wear assessment. *Journal of Reinforced Plastics and Composites*, *36*(19), 1403–1420.
2. Wang, G. *et al.* (2018) 'Research on milling strategies to reduce delamination damage during machining of holes in CFRP / Ti stack', *Composite Structures*. Elsevier, 200(37), pp. 679688.doi:10.1016/j.compstruct.2018.06.011
3. Karpat, Y. and Bahtiyar, O. (2015) 'Comparative analysis of PCD drill designs during drilling of CFRP laminates', *Procedia CIRP*. Elsevier B.V., 31, pp. 316–321. doi: 10.1016/j.procir.2015.03.094.
4. Klotz, S. *et al.* (2017) 'Experimental investigation of clamping systems and the resulting change of cutting conditions while drilling carbon fiber reinforced plastics', *Procedia CIRP*. The Author(s), 62, pp. 15–20. doi: 10.1016/j.procir.2016.06.089.
5. Heisel, U., & Pfeifroth, T. (2012). Influence of point angle on drill hole quality and machining forces when drilling CFRP. *Procedia CIRP*, *1*(1), 471–476.
6. Sadek, A., Meshreki, M. and Attia, M. H. (2012) 'CIRP Annals - Manufacturing Technology Characterization and optimization of orbital drilling of woven carbon fiber reinforced epoxy laminates', *CIRP Annals - Manufacturing Technology*. CIRP, 61(1), pp. 123–126. doi: 10.1016/j.cirp.2012.03.089.
7. Lissek, F., Tegas, J. and Kaufeld, M. (2016) 'Damage quantification for the machining of CFRP: An introduction about characteristic values considering shape and orientation of drilling-induced delamination', *Procedia Engineering*. Elsevier B.V., 149(June), pp. 2–16. doi: 10.1016/j.proeng.2016.06.632.
8. Hintze Wolfgang, W., Hartmann, D., & Schütte, C. (2011). Occurrence and propagation of delamination during the machining of carbon fibre reinforced plastics (CFRPs) - An experimental study. *Composites Science and Technology*, *71*(15), 1719–1726.
9. Raj, D. S. and Karunamoorthy, L. (2015) 'Materials and Manufacturing Processes Study of the Effect of Tool Wear on Hole Quality in Drilling Cfrp to Select a Suitable Drill for Multi-Criteria Hole Quality', (March), pp. 37–41. doi: 10.1080/10426914.2015.1004713.
10. Klocke, F. *et al.* (2017) 'Experimental investigation of the hole accuracy , delamination , and cutting force in piercing of carbon fiber reinforced plastics', *Procedia CIRP*. The Author(s), 66, pp. 215–220. doi: 10.1016/j.procir.2017.03.297.
11. Sorrentino, L., Turchetta, S. and Bellini, C. (2017) 'A new method to reduce delaminations during drilling of frp laminates by feed rate control', *Composite Structures*. doi: 10.1016/j.compstruct.2017.12.005.
12. Wang, Y. G., Sun, C. Y., Yan, X. P., & Jiang, K. R. (2011). *Study on the Surface Delamination in Milling Carbon Fiber Reinforced Plastic with PCD Tool. Advanced Materials Research, 381, 1–5.*
13. Davim, J. P. *et al.* (2011) 'A study aimed at minimizing delamination during drilling of CFRP composites', *Journal of Composite Materials*, 45(22), pp. 2359–2368. doi: 10.1177/0021998311401087.
14. Tsao, C. C. and Chiu, Y. C. (2011) 'International Journal of Machine Tools & Manufacture Evaluation of drilling parameters on thrust force in drilling carbon fiber reinforced plastic (CFRP) composite laminates

using compound core-special drills', *International Journal of Machine Tools and Manufacture*. Elsevier, 51(9), pp. 740–744. doi: 10.1016/j.ijmachtools.2011.05.004.

15. Isbilir, O. and Ghassemieh, E. (2012). Delamination and wear in drilling of carbon-fiber reinforced plastic composites using multilayer TiAlN/TiN PVD-coated tungsten carbide tools. 'Journal of Reinforced Plastics and Composites'. doi: 10.1177/0731684412444653.
16. Bahtiyar, O. (2012) 'Journal of Materials Processing Technology Drilling thick fabric woven CFRP laminates with double point angle drills', 212, pp. 2117–2127. doi: 10.1016/j.jmatprotec.2012.05.017.
17. Hintze, W., & Hartmann, D. (2013). *Modeling of Delamination During Milling of Unidirectional CFRP*. Procedia CIRP, 8, 444-449.
18. Krishnaraj, V., Prabukarthi, A., Ramanathan, A., Elanghovan, N., Kumar, M. S., Zitoune, R., & Davim, J. P. (2012). Optimization of machining parameters at high speed drilling of carbon fiber reinforced plastic (CFRP) laminates. *Composites Part B: Engineering*, *43*(4), 1791–1799.