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Percentage Area Reduction of Uncut Fibre of Drilling Pineapple Leaf Fibre Reinforced Composites with Peck Drilling Canned Cycle Method

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ABSTRACT

The effectiveness of utilizing the peck drilling canned cycle to minimize hole delamination has been demonstrated. However, its potential to reduce uncut fiber resulting from fiber fracture and pull-out has not been fully recognized, particularly in drilling natural fiber-reinforced polymer composites. Therefore, this study investigated the performance of this established method and compared it with the conventional drilling approach using a stepped geometry drill bit, which is purported to minimize hole delamination and, consequently, reduce uncut fiber. A series of hole-making processes were carried out according to a Completely Randomized Design (CRD) experimental plan. Different feed movements were employed to elicit responses, specifically the extent of uncut fiber area. The findings indicate that employing the established method could reduce uncut fibers by approximately 18.6%, representing a 2% enhancement compared to the alternative approach. Hence, the peck drilling canned cycle strategy offers a promising and cost-effective alternative to using specialized drill bits or high-performance cutting tools.

KEYWORDS: *Hole-making process, Peck drilling canned cycle, Uncut fibre, Pineapple leaf fibres.*

NOMENCLATURE

ANOVA	Analysis of Variances
ANN	Artificial Neural Networks
CFRP	Carbon Fibres Reinforced Plastics
CNC	Computer Numerical Control
CRD	Completely Randomized Design
GFRP	Glass Fibres Reinforced Plastics
HSS	High Speed Steel
PALFs	Pine-apple Leaf Fibres
PMC	Polymer Matrix Composites
RPM	Rotation per Minutes
f	Feed Movements
N	Spindle Speed
Q	Drilling step length

1.0 INTRODUCTION

Composites are attractive materials for steel and aluminium substitution. Its tailor-made capabilities yield a high strength-to-weight ratio, design flexibility, durability, corrosion and thermal resistance, customization, and lightweight and endurance material [1]. Thus, it allows its utilization in broad areas of application such as aerospace, automotive, marine, energy, construction and infrastructure [2].

The most commercially available composite is polymer matrix composite (PMC). PMC comprises a matrix and reinforcement. Thermoplastic or thermosetting polymers are widely used as matrices, while fibres are employed as reinforcement [3-4]. Synthetic fibres like glass and Aramid fibre are tested and commercially available. However, employing natural fibres becomes a viable option for synthetic ones when considering their environmental consequences [5]. It is because of its qualities that are similar to those of synthetic [6-7] and readily sustainable sources [8-9], even though it still has particular problems with its mechanical properties [10]. However, some parts of the automobile industry have used natural fibre-reinforced composites [11-12].

One natural resource for composite ingredients is Pineapple leaf fibres (PALFs) that are farmed to provide one acceptable natural fibre as reinforcements, predominantly when composed with Polyester [13]. Nevertheless, the better elastic properties of PALFs lead to high strain resistance [14] which, in turn, would upset machinability [15] due to the bounce effect.

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Accordingly, it could step up thrust forces and heat generation; consequently, it would deteriorate the surface and sub-surface [16]. Thus, it has been an attractive challenge to produce holes of good quality on this kind of composite material. One challenge it had to cope with was avoiding excessive uncut fibre. Uncut fibres are of importance in drilling composite materials because they enable uplifting tension in the short sections [17], and they are ordinarily identical to delamination [18-19]. As an aftereffect, product assembly would be effortful. Therefore, minimizing uncut fibres being drilling composite materials, is essential to guarantee damage promotion.

Jabbaripour et al. found that incremental feed rates would broaden the area of uncut fibres when drilling thermoplastic-reinforced carbon fibre. In comparison, the rise in cutting speed would lower the uncut area [18]. The study was carried out using coated carbide tools that performed continuous drilling. In addition, Malik et al. utilized a variety of drill bits' material. They discovered no uncut fibre during drilling with a solid carbide coated with Balinit® Helica cutting tool at 15,000 rpm of drilling rotational speed [20]. Furthermore, Kwon et al. conclude that higher feed rates would reduce the uncut fibre ratio [21]. However, this finding was revealed after continuously drilling a composite reinforced carbon with a prepared stepped geometry of uncoated carbide drill bits. In general, the cutting tool materials and geometry proved to play a significant role in reducing uncut fibre. However, those strategies would be unbeneficial, attributing to high cutting tool acquiring costs.

There is a technique commonly adapted when drilling deep holes or difficult-to-machined materials. This technique is known as the peck drilling canned cycle. It is recognized as a thrust forces reduction method [22]. However, the employability of this technique in drilling composite materials, particularly for reducing uncut fibres, still needs to be proven. Kently utilized the technique mentioned above coupled with Artificial Neural Network (ANN) to examine the damage factor in drilling Glass Fibre Reinforced Plastics (GFRP) [23]. However, the influence of pecking length shows an inconsistent trend as cutting speed increases. Besides, Phalape et al. [24] also employed a peck drilling strategy in drilling Carbon Fibre Reinforced Plastics (CFRP). The effective pecking length needed to be clearly defined, although it could help improve hole quality. In general, all the previous reports are only concerned about the advantages of the peck drilling strategy on drilling synthetic-based composites. Meanwhile, its application for drilling natural-based composites has yet to be exposed well. Accordingly, in this study, the technique would be adapted to help the area of uncut fibre remain less and compared with the promising strategy promoted in the previous report [21] for drilling natural fibre-reinforced plastics such as Pineapple Leaf Fibres (PALFs) reinforced plastics.

2.0 METHODS

2.1 Material Preparation

Multiple experimental specimens were crafted in the form of composite plates, each measuring 300 mm x 150 mm x 7.5 mm. These plates comprised epoxy resin as the matrix material, reinforced with PALFs and augmented with a hardener additive. The PALFs were spun and woven into a mat with a crossed-90° orientation and a thickness of 2.25 mm. The employing of the hand lay-up technique, a composite plate was fabricated with the matrix and woven fiber weight percentages set at 70% and 30%, respectively. Figure 1 illustrates the resulting composite experimental specimen.

Figure 1: Experimental specimen

2.2 Experimental Design

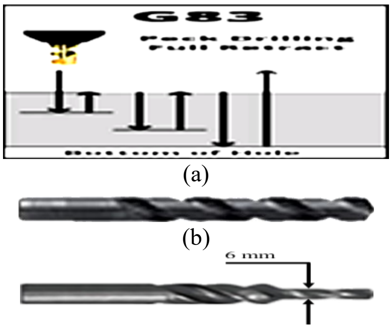
In accordance with the study's objectives, a Completely Randomized Design (CRD) was chosen as the experimental design. To facilitate comparison, machining conditions were adjusted based solely on one key factor, namely the feed movement. This choice was made because it plays a crucial role in minimizing hole damage, particularly hole delamination. Therefore, the feed movement (f) was varied within the range of 0.1 to 0.6 mm/rev for this study. Meanwhile, the speed (N) was maintained constant at 2000 RPM. The experimental setup is outlined in Table 1. Additionally, for the peck drilling canned cycle strategy, the drilling step (Q) utilized was set equivalent to the thickness of the reinforced mat, approximately 2.25 mm. This was done to ensure that only a small portion of the reinforcement was cut by the tool tip, thereby preventing damage to the inter-laminar bonding of the composite.

Table 1: The experimental lay-out

Exp. No	Speed (RPM)	Feed (mm/min)	Responses Uncut Fibres (mm)	
			Peck Drilling	Continuous Drilling
1	2000	0.1		
2		0.3		
3		0.6		

2.3 Experimental Set-up

The hole-making procedure aimed to create through holes. Peck drilling, employing a G83 code (depicted in Figure 2(a)), utilized an 11 mm conventional HSS twist drill bit (shown in Figure 2(b)), while continuous drilling employed a stepped geometry HSS twist drill bit as depicted in Figure 2(c).



(a)

(b)

(c)

Figure 2: Cutting tools and drilling strategies employed in the study; a) peck drilling stage using G83 code [26], b) a conventional twist drill bits used with peck drilling cycle strategy and c) continuous drilling with a stepped geometry of twist drill bits

Both methods were executed using a Feeler Computer Numerical Control (CNC) Machining Centre model VMP-40A, capable of operating at a maximum spindle speed of 3200 RPM and a feed rate of 2 m/min. All observed holes were examined using a handheld digital microscope with a maximum magnification of 500x. The Digimizer™ image processing software, in its trial version, was employed to quantify the uncut fiber areas within the captured images of the holes. Additionally, the percentage of uncut fibers within the holes was determined by comparing the area attributable to uncut fibers to the total area of the perfectly cut holes. Subsequently, all collected data were subjected to analysis using One-way Analysis of Variances (ANOVA) with a 95% confidence level, Fisher Individual Test approaches, and regression analysis to verify the findings.

3.0 RESULTS AND DISCUSSION

3.1 Percentage of Hole's Uncut Fibre at Varying Feed Movements

The extent of uncut fibers is typically influenced by factors such as feed rates, lubrication, and cutting speeds [18-19]. Therefore, in assessing the effectiveness of two drilling methods in this investigation, the feed movement was regarded as a factor stimulating the response, which is the percentage area of uncut fibers. Consequently, a sequence of hole-making operations was conducted, and the percentage area of uncut fibers within the holes was measured. The outcomes of these measurements are presented in Figure 3.

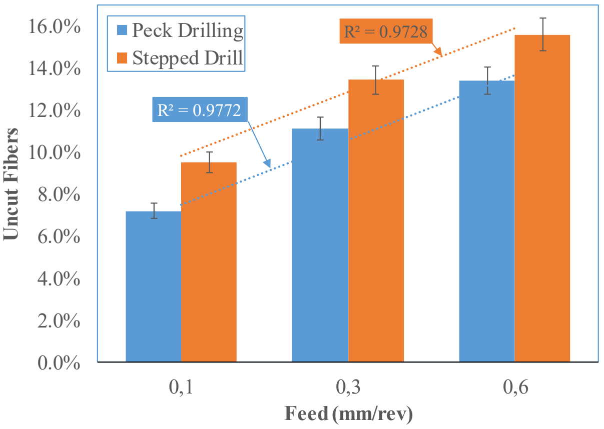
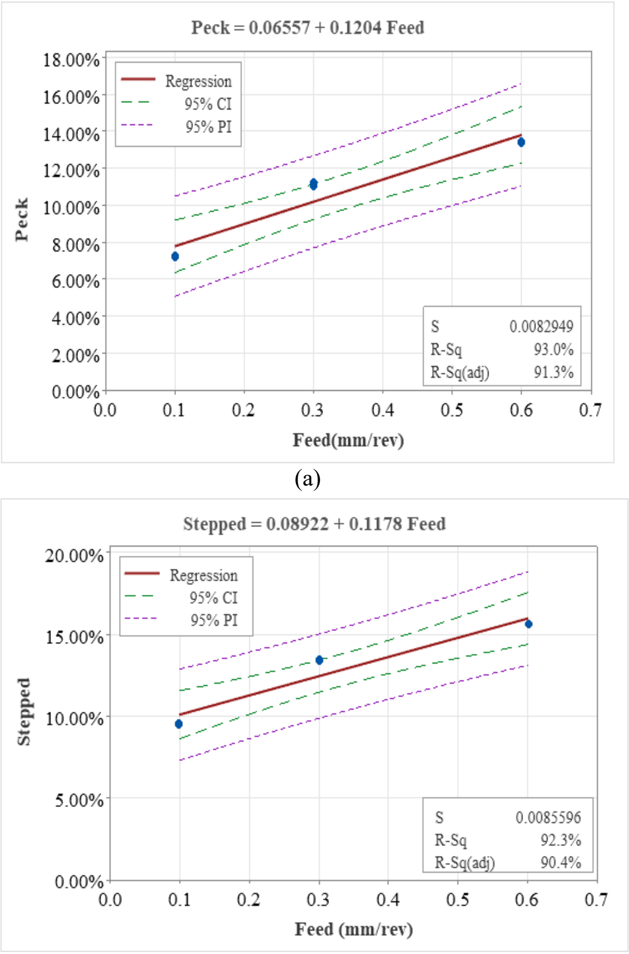


Figure 3: Effect of feed movements toward percentage area of hole's uncut fibers

As illustrated in Figure 3, the implementation of the peck drilling canned cycle strategy results in a decrease in the percentage area of uncut fibers. On average, an approximate reduction of 2.3% is observed with incremental feed movements. However, prior to discussing the efficacy of the peck drilling canned cycle strategy, a statistical analysis was necessary. This involved conducting a one-way ANOVA and linear regression analysis to validate the findings. The results of the statistical analysis, including Fisher's comparison, are outlined in Table 2.

From Table 2, it is evident that there is a notable distinction between the two assessed strategies across different feed movements, as indicated by the adjusted R-values being less than 0.05. Additionally, the regression analysis, conducted using the Fitted Line Plot approach as depicted in Figure 4. It aims to ascertain whether the increase in feed movements adheres to a linear trend for both, evaluation strategies or deviates from it.

As can be seen from Figure 4, the adjusted coefficient determination (i.e. adjusted-R^2) for both strategies have magnitudes between 91.3% and 90.4% for either peck drilling canned cycle and continuous drilling with stepped drill bits, respectively. The selected adjusted-R^2 as the indicator is owing to provide an unbiased analysis in regression [27]. Thus, the analysis result marks a robust correlation between dependent and dependent variables in this study [27]. Furthermore, it can be underlined that an increase in feed movement would influence the percentage areas of the hole's uncut fibres. Thus, it can be put the lid on that this finding agrees with the previous reports [28]. Accordingly, it can be inferred that the results presented in Figure 2 reflect actual observation either within or with the group for all examined feed movements. Thus, the peck drilling canned cycle strategy notably surpasses the performance of continuous drilling with stepped twist drill geometry in lowering the percentage area of uncut fibres.



(a)

(b)

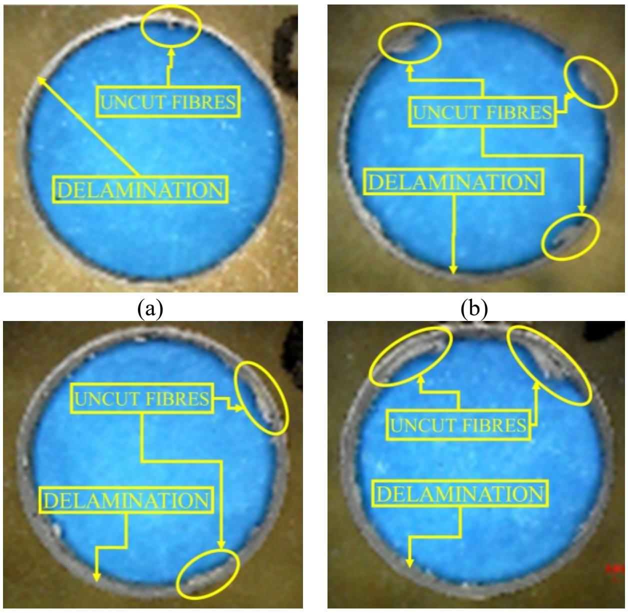
Figure 4: Analysis of Linear Regression results of a) peck drilling canned cycle and b) continuous drilling with stepped geometry of tool bits

Table 2: ANOVA results between continuous drilling with stepped drill bit geometry and peck drilling canned cycle for cumulative feed movements

Factor	Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted ρ-Value
0.1	Stepped - Peck	0.023202	0.00052	(0.020964, 0.025439)	44.61	0.001
0.3		0.023193	0.000978	(0.018985, 0.027401)	23.71	0.002
0.6		0.021981	0.000283	(0.020762, 0.023199)	77.57	0.000

Simultaneous confidence level = 95.00%

Moreover, compared to continuous drilling utilizing stepped drill geometry, approximately an 18.6% reduction of uncut fibre area can be made on average. In other words, only around 11% of the hole's area is left uncut due to improperly cutting off the fibres. In contrast, using continuous drilling with stepped drill geometry, 13% of the hole's area remains uncut. Figure 5 shows a discrepancy in uncut fibre volume between evaluated methods. Nevertheless, as feed movement increases, the volume of uncut fibres for both methods tends to escalate, as can be seen in Figure 5(c) and Figure 5(d).



(a) (b)
(c) (d)

Figure 5: Apparitions of uncut fibres and distinction magnitude of hole delamination at difference conditions such as f=0.1 mm/rev for a) peck drilling canned cycle and b) continuous drilling with stepped drill bits' geometry and f=0.6 mm/rev for c) peck drilling canned cycle and d) continuous drilling with stepped drill bits' geometry

Several arguments might be possible as influencing factors. The use of worn tools, improper selection of machining variables, and design of cutting tools geometry, as well as the fibres' inherent abrasive properties, are attributable to the leading cause of uncut fibres [28-29]. In the case of this study, improper design of tool geometry could be the prevailing reason for inferior performance of continuous drilling with stepped drill bits. Thus, it can be argued that the relatively superior performance shown by stepped drill tools in reducing delamination induced by uncut fibres, as claimed in previous reports [30-31] might not be applicable for all conditions, including in drilling polymer-based composite reinforced PALFs. Therefore, the findings in this study could open new windows in seeking alternatives for eliminating hole delamination in drilling composite materials, especially for those made of natural fibres.

Lastly, the better performance of employing the peck drilling canned cycle method in reducing the occurrence of uncut fibres is presumably due to its capability to reduce thrust forces by only a tiny portion of the material being removed for each peck, hindering chip build, thus enhancing the quality of the drilled holes [32]. Higher thrust forces would induce the formation of delamination [20], [33-34] poor surface finish [32], and tool wear acceleration [35]. In contrast, the use of small-diameter drill bits for providing pre-penetration action might be beneficial to scale down the magnitude of thrust forces [36]. However, the more significant dimension of the descendant diameter would block the chips' evacuation out of the holes [37]. It would, in turn, propagate the excessive heat. In addition, it shortens the tool life and weakens the interfacial matrix-reinforced strength that would be attributable to ploughing rather than the intended shearing mechanism that could ensure the fibres are completely cut off.

3.2 Progression of Hole's Uncut Fibre Areas Percentage Toward Different Feed Movement

Maintaining uniform quality throughout the entire hole-making process poses a challenge. Nonetheless, there remains the opportunity to uphold quality standards as the number of holes increases, contingent upon finely adjusting the machining parameters. This necessitates implementing an adaptive machining approach, which may prove to be a daunting task. It implies that the quality of the hole may be inconsistent as several holes progresses due to tool wear progression, for instance [35]. Hence, the System of Limits and Fits is commonly utilized as a standard in conventional hole-making procedures. Moreover, a set of holes has been analyzed to contrast the effectiveness of the Peck Canned Cycle drilling technique with continuous drilling employing a stepped twist drill bit in minimizing the percentage of uncut fiber area within the hole. This comparison aims to ascertain the consistent performance of each method with the increasing number of holes drilled. The outcomes are depicted in Figure 6.

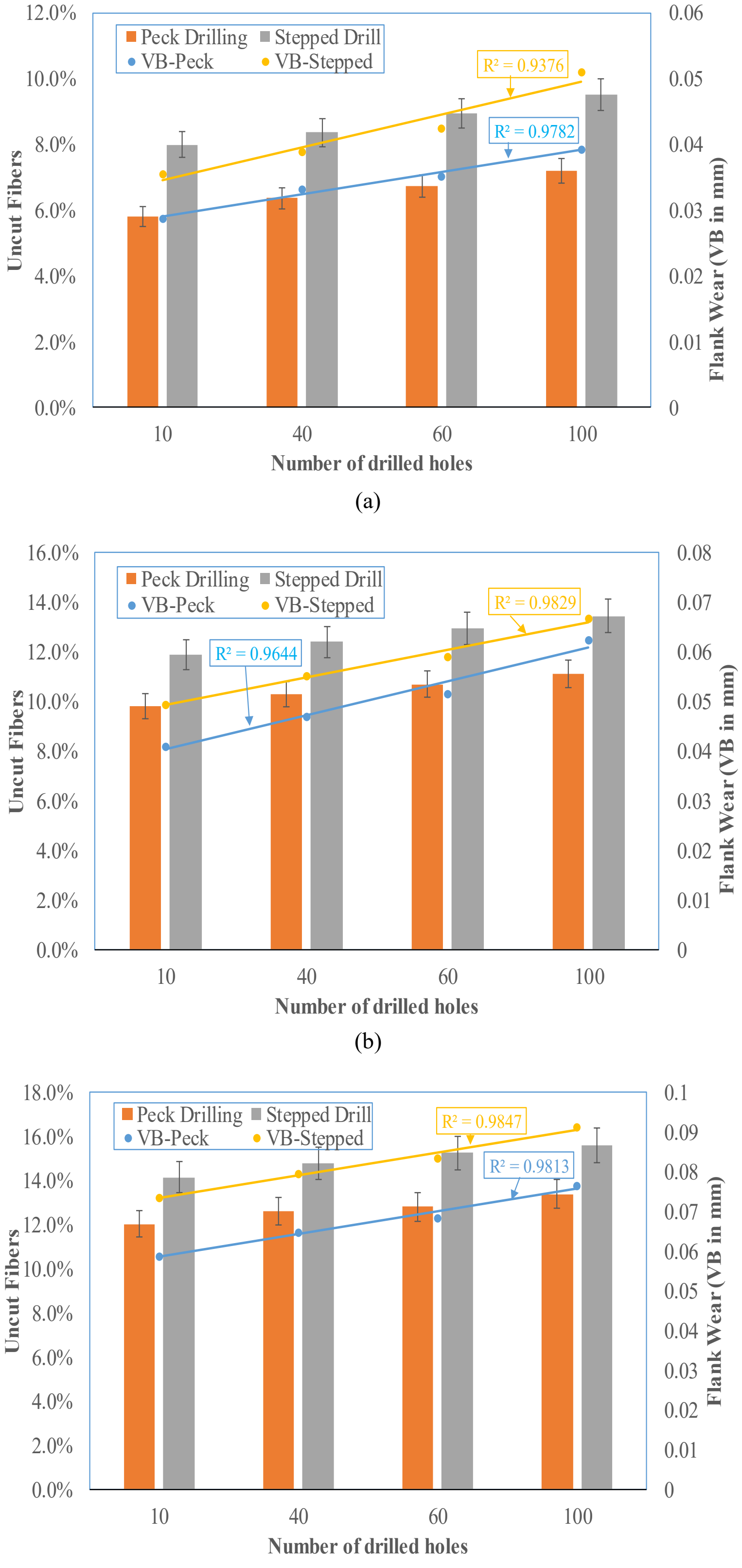


Figure 6: Progression of percentage area of uncut fibres as consequences of tool wear progression

Table 3: ANOVA results based on fisher individual tests for differences of means

Feed	Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted ρ-Value
0.1 mm/rev	Peck Drilling Cycles					
	40 - 10	0.002832	0.000287	(0.002036, 0.003628)	9.88	0.001
	60 - 40	0.001918	0.000287	(0.001122, 0.002714)	6.69	0.003
	100 - 60	0.002419	0.000287	(0.001623, 0.003215)	8.44	0.001
	Stepped Twist Drill					
	40 - 10	0.001882	0.000417	(0.000724, 0.003040)	4.51	0.011
	60 - 40	0.003121	0.000417	(0.001963, 0.004279)	7.48	0.002
	100 - 60	0.002953	0.000417	(0.001795, 0.004111)	7.08	0.002
0.3 mm/rev	Peck Drilling Cycles					
	40 - 10	0.00258	0.000326	(0.001674, 0.003486)	7.91	0.001
	60 - 40	0.00204	0.000326	(0.001134, 0.002946)	6.25	0.003
	100 - 60	0.002296	0.000326	(0.001390, 0.003202)	7.04	0.002
	Stepped Twist Drill					
	40 - 10	0.002828	0.000277	(0.002060, 0.003596)	10.23	0.001
	60 - 40	0.002918	0.000277	(0.002151, 0.003686)	10.56	0
	100 - 60	0.002595	0.000277	(0.001827, 0.003362)	9.38	0.001
0.6 mm/rev	Peck Drilling Cycles					
	40 - 10	0.003165	0.000364	(0.002154, 0.004177)	8.69	0.001
	60 - 40	0.001012	0.000364	(0.000001, 0.002023)	2.78	0.05
	100 - 60	0.003188	0.000364	(0.002177, 0.004200)	8.75	0.001
	Stepped Twist Drill					
	40 - 10	0.003474	0.00043	(0.002279, 0.004668)	8.07	0.001
	60 - 40	0.002508	0.00043	(0.001313, 0.003703)	5.83	0.004
	100 - 60	0.001829	0.00043	(0.000634, 0.003024)	4.25	0.013

Simultaneous confidence level = 84.70%

Figure 6 illustrates a rise in the percentage area of uncut fibers as the number of holes increases for both assessed methods, across different feed movements. Additionally, Figure 6 also indicates the progression of flank wear with the increase in the number of holes. However, prior to further discussion, the results needed validation through linear regression and one-way ANOVA to confirm the authenticity of the differences observed among the responses. The ANOVA outcomes are presented in Table 3. Meanwhile, the linear regression analysis is embedded in Figure 6, showcasing the coefficient determination (R^2).

The results of the ANOVA in Table 3 reveal a notable difference in the percentage of uncut fibres between the two strategies. This difference is evident from the R-values, which are consistently below 0.05, signifying a 95% confidence level. Thus, it can be inferred that the variations observed in Figure 6 accurately represent the responses. Additionally, the coefficient determinations depicted in Figure 6 indicate a linear trend in the incremental percentage of uncut fibres, supported by the excellent fit with high R-squared values [38]. Hence, as the number of holes increases in drilling PALF-reinforced composites, there is a corresponding increase in uncut fibres. This suggests that both drilling methods face challenges in maintaining consistent hole quality, primarily because the drill bits become dull over time, resulting in higher cutting forces needed to shear the inter-laminar layers of the composites [39]. Bearing in mind that even though the cutting tools operate within wear limits, continued use may result in a decrease in sharpness, leading to potential of hole damage, as illustrated in Figure 6.

4.0 CONCLUSION

This research examined the efficacy of employing the peck drilling canned cycle versus continuous drilling using a step drill bit geometry for drilling holes in PALF-reinforced composites. Hole drilling experiments were conducted, with variations in the feed rate as a key parameter. Subsequently, the drilled holes were assessed and analyzed to determine the percentage of uncut fibers. The findings revealed that the peck drilling strategy resulted in an average decrease of 18.6% in the uncut fiber percentage compared to continuous drilling. Additionally, statistical analysis indicated that the uncut fiber percentage for both methods increased with an increasing number of holes, suggesting challenges in maintaining consistent hole quality across multiple holes. Nevertheless, the study concluded that employing the peck drilling canned cycle was a practical and cost-efficient approach to minimize uncut fiber in PALF composite drilling. Despite the requirement for high-performance drill bits or specialized geometry, this can be expensive, being drilling composite materials.

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REFERENCES

[1] Pereira, A.B. & Fernandes, F.A. (2019). Introductory Chapter: The Importance of Composites in the World. In *Renewable and Sustainable Composites*. IntechOpen, doi: 10.5772/intechopen.89427.

[2] Amaechi, C.V., Agbomerie, C.O., Orok, E.O. & Ye, J. (2020). Economic aspects of fiber reinforced polymer composite recycling. *Encyclopedia of renewable and sustainable materials*, 377-397. doi: 10.1016/B978-0-12-803581-8.10738-6.

[3] Ahmedabad Textile Industry's Research Association (ATIRA) (2021). Composite Materials: Types of Composites and Applications, in https://atira.in/composite-materials-guide/ (accessed Aug. 10, 2023).

[4] Aimplas (2022). Types of composite materials, https://www.aimplas.net/blog/types-of-composite-materials/ (accessed Sep. 15, 2023).

[5] Joshi, S.V., Drzal, L.T., Mohanty, A.K. & Arora, S. (2004). Are natural fiber composites environmentally superior to glass fiber reinforced composites?. *Composites Part A: Applied science and manufacturing*, *35*(3), 371-376. doi: 10.1016/j.compositesa.2003.09.016.

[6] Ticoalu, A., Aravinthan, T. & Cardona, F. (2010). A review of current development in natural fiber composites for structural and infrastructure applications. In *Proceedings of the southern region engineering conference (SREC 2010). Incorporating the 17th Annual International Conference on Mechatronics and Machine Vision in Practice, M2VIP 2010*, 113-117.

[7] Wambua, P., Ivens, J. & Verpoest, I. (2003). Natural fibres: can they replace glass in fibre reinforced plastics?. *Composites science and technology*, *63*(9), 1259-1264. doi: 10.1016/S0266-3538(03)00096-4.

[8] Ayensu, A. (2000). Interfacial debonding of natural-fibre reinforced composites. *Science Vision*, *6*(1), 25-33.

[9] Verma, D., Gope, P.C., Shandilya, A., Gupta, A. & Maheshwari, M.K. (2013). Coir fibre reinforcement and application in polymer composites. *J. Mater. Environ. Sci*, *4*(2), 263-276.

[10] Saheb, D.N. & Jog, J.P. (1999). Natural fiber polymer composites: a review. *Advances in Polymer Technology: Journal of the Polymer Processing Institute*, *18*(4), 351-363. doi: 10.1002/(SICI)1098-2329(199924)18:4<351::AID-ADV6>3.0.CO;2-X.

[11] Lotfi, A., Li, H., Dao, D.V. & Prusty, G. (2021). Natural fiber–reinforced composites: A review on material, manufacturing, and machinability. *Journal of Thermoplastic Composite Materials*, *34*(2), 238-284. doi: 10.1177/0892705719844546.

[12] Faruk, O., Bledzki, A.K., Fink, H.P. & Sain, M. (2014). Progress report on natural fiber reinforced composites. *Macromolecular Materials and Engineering*, *299*(1), 9-26. doi: 10.1002/mame.201300008.

[13] Mishra, S., Misra, M., Tripathy, S.S., Nayak, S.K. & Mohanty, A.K. (2001). Potentiality of pineapple leaf fibre as reinforcement in PALF-polyester composite: Surface modification and mechanical performance. *Journal of Reinforced Plastics and Composites*, *20*(4), 321-334. doi: 10.1177/073168401772678779.

[14] Mishra, S., Mohanty, A.K., Drzal, L.T., Misra, M. & Hinrichsen, G. (2004). A review on pineapple leaf fibers, sisal fibers and their biocomposites. *Macromolecular Materials and Engineering*, *289*(11), 955-974. doi: 10.1002/mame.200400132.

[15] Zhang, K., Wang, K., Liu, Z. & Xu, X. (2020). Strain rate of metal deformation in the machining process from a fluid flow perspective. *Applied Sciences*, *10*(9), 3057. doi: 10.3390/app10093057.

[16] Sun, X., Yao, P., Qu, S., Yu, S., Zhang, X., Wang, W. et al. (2022). Material properties and machining characteristics under high strain rate in ultra-precision and ultra-high-speed machining process: A review. *The International Journal of Advanced Manufacturing Technology*, *120*(11-12), 7011-7042. doi: 10.1007/s00170-022-09111-5.

[17] Jaiswal, A.P. & Park, H.W. (2022). Experimental and analytical examination of multidirectional carbon fiber–reinforced polymers for uncut fibers and their distributions during drilling. *The International Journal of Advanced Manufacturing Technology*, *123*(3-4), 1323-1339. doi: 10.1007/s00170-022-10215-1.

[18] Jabbaripour, B., Ansari, M.J. & Taheri, A. (2021). Investigating delamination, uncut fibers, tolerances and surface topography in high speed Drilling of Polypropylene Composite Reinforced with carbon fibers and calcium carbonate Nano-particles. *International Journal of Material Forming*, *14*(6), 1417-1437., doi: 10.1007/s12289-021-01639-3.

[19] Tran, Q.P., Tsai, M.C., Hsiao, T.C. & Huang, S.C. (2020). Experimental influence of twist angle and cryogenic gas on quality of drilled hole in carbon fiber reinforced plastic composites. *Measurement and Control*, *53*(5-6), 943-953. doi: 10.1177/0020294020903323.

[20] Malik, K., Ahmad, F., Keong, W.T. & Gunister, E. (2022). The effects of drilling parameters on thrust force, temperature and hole quality of glass fiber reinforced polymer composites. *Polymers and Polymer Composites*, *30*, 09673911221131113. doi: 10.1177/09673911221131113.

[21] Kwon, B.C., Mai, N.D.D., Cheon, E.S. & Ko, S.L. (2020). Development of a step drill for minimization of delamination and uncut in drilling carbon fiber reinforced plastics (CFRP). *The International Journal of Advanced Manufacturing Technology*, *106*, 1291-1301. doi: 10.1007/s00170-019-04423-5.

[22] Eltaggaz, A. & Deiab, I. (2019). Comparison of between direct and peck drilling for large aspect ratio in Ti-6Al-4V alloy. *The International Journal of Advanced Manufacturing Technology*, *102*, 2797-2805. doi: 10.1007/s00170-019-03314-z.

[23] Kentli, A. (2011). Experimental study on peck drilling of GFRP and prediction of drilling-induced damage using ANN. *Scientific Research and Essays*, *6*(7), 1546-1554. doi: 10.5897/SRE10.663.

[24] Phapale, K., Singh, R. & Singh, R.K.P. (2020). Comparative assessment of delamination control techniques in conventional drilling of CFRP. *Procedia*

Manufacturing, *48*, 123-130. doi: 10.1016/j.promfg.2020.05.028.

[25] Tamura, S. & Matsumura, T. (2021). Delamination-free drilling of carbon fiber reinforced plastic with variable feed rate. *Precision Engineering*, *70*, 70-76. doi: 10.1016/j.precisioneng.2021.01.003.

[26] Brandon Fowler (2023), G83 CNC Code Explained: An Easy Intro for Beginners [Peck Drilling]. *Machinistguides*, https://www.machinistguides.com/g83-code/.

[27] Stephen Allwright (2003). Good R-Squared value. https://stephenallwright.com/good-r-squared-value/ (accessed July, 12, 2023).

[28] Jagadeesh, P., Rangappa, S.M., Suyambulingam, I., Siengchin, S., Puttegowda, M., Binoj, J.S., et al. (2023). Drilling characteristics and properties analysis of fiber reinforced polymer composites: A comprehensive review. *Heliyon*, 9(3), e14428, doi: 10.1016/j.heliyon.2023.e14428.

[29] Pervaiz, S., Kannan, S., Huo, D. & Mamidala, R. (2020). Ecofriendly inclined drilling of carbon fiber-reinforced polymers (CFRP). *The International Journal of Advanced Manufacturing Technology*, *111*, 2127-2153. doi: 10.1007/s00170-020-06203-y.

[30] Hocheng, H. & Tsao, C. C. (2006). Effects of special drill bits on drilling-induced delamination of composite materials. *International Journal of Machine Tools and Manufacture*, *46*(12-13), 1403-1416. doi: 10.1016/j.ijmachtools.2005.10.004.

[31] Bajpai, P.K., & Singh, I. (2013). Drilling behavior of sisal fiber-reinforced polypropylene composite laminates. *Journal of Reinforced Plastics and Composites*, *32*(20), 1569-1576. doi: 10.1177/0731684413492866.

[32] Boughdiri, I., Giasin, K., Mabrouki, T. & Zitoune, R. (2021). Effect of cutting parameters on thrust force, torque, hole quality and dust generation during drilling of GLARE 2B laminates. *Composite Structures*, *261*, 113562. doi: 10.1016/j.compstruct.2021.113562.

[33] Bolat, Ç., Karakılınç, U., Yalçın, B., Öz, Y., Yavaş, Ç., Ergene, B., et al. (2023). Effect of drilling parameters and tool geometry on the thrust force and surface roughness of aerospace grade laminate composites. *Micromachines*, *14*(7), 1427. doi: 10.3390/mi14071427.

[34] Mahdi, A., Turki, Y., Habak, M., Salem, M. & Bouaziz, Z. (2020). Experimental study of thrust force and surface quality when drilling hybrid stacks. *The International Journal of Advanced Manufacturing Technology*, *107*, 3981-3994. doi: 10.1007/s00170-020-05252-7.

[35] Uddin, M., Basak, A., Pramanik, A., Singh, S., Krolczyk, G.M. & Prakash, C. (2018). Evaluating hole quality in drilling of Al 6061 alloys. *Materials*, *11*(12), 2443. doi: 10.3390/ma11122443.

[36] Ramesh, M., Palanikumar, K. & Reddy, K.H. (2014). Experimental investigation and analysis of machining characteristics in drilling hybrid glass-sisal-jute fiber reinforced polymer composites. In *5th international & 26th all india manufacturing technology, design and research conference AIMTDR*. 461-1: 461-6.

[37] DIYDATA (2023). Drillbits - the different types. https://www.diydata.com/tool/drillbits/drillbits.php (accessed May 24, 2023).

[38] Nau, R. (2020). Statistical forecasting: notes on regression and time series analysis. https://people.duke.edu/~rnau/rsquared.htm (accessed July 12, 2023).

[39] In the Loupe (2017). Overcoming Composite Holemaking Challenge. *Machinist Blog*, https://www.harveyperformance.com/in-the-loupe/composite-holemaking-challenges/.