INFLUENCE OF MILLLING PROCESS PARAMETER WITH VARY ENDMILL COATING ON CUTTING FORCE DURING MILLING OF CFRP

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Abstract

During the milling of Carbon Fiber Reinforced Polymer (CFRP), the cutting force is influenced by various process parameters. CFRP is a composite material composed of carbon fibers embedded in a polymer matrix, and its machining behavior is different from traditional metals. In milling Carbon Fiber Reinforced Polymer (CFRP), the cutting force components (F_x, Fy, and Fz) act in different directions relative to the machining process. CFRP is a composite material with anisotropic properties; the cutting forces may vary significantly depending on the orientation of the carbon fibers relative to the cutting tool. Careful consideration of the fiber orientation and proper tool path planning can help manage the cutting forces and achieve desired machining results with minimal damage to the CFRP workpiece. In CFRP milling, the Fy force is typically the dominant component since it includes the weight of the tool and the forces required to lift the material and move the tool through the workpiece. Reducing the Fy force is essential to minimize the risk of delamination and surface damage in CFRP components. The F_x and Fz forces are influenced by the factors mentioned earlier, such as cutting speed, feed rate, and depth of cut, tool geometry, fiber orientation, and machine rigidity. Present study has been done to optimize the process parameters during machining of CFRP by CNC end milling process. Three input process parameters namely cutting speed, feed and depth of cut were chosen as variables to study the process performance in terms of cutting force. Cutting forces have been examined by tool dynamometer.

Keywords: Machining, Milling, CFRP, Cutting Force

DOI: 10.48047/ecb/2023.12.8.553

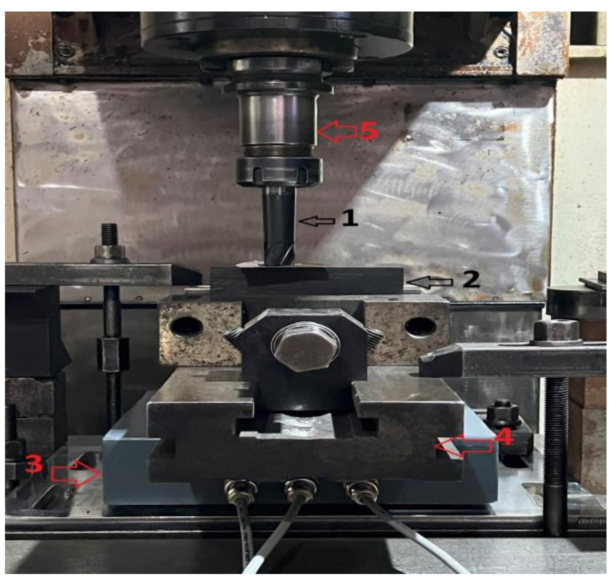
1. Introduction

This paper presents an experimental study of end milling of CFRP with DLC coated tool, AlCrN coated tool and uncoated tool under dry cutting conditions. The cutting force variation along with input machining parameters were analyzed and discussed. The aim of this research paper is to investigate the best combination of machining parameters i.e. cutting speed, feed, and depth of cut on cutting force for machining CFRP material.Fiber reinforced plastics are among the most high-performance materials in the field of light-weight design due to their exceptional weight-specific qualities. They are especially intriguing for structural components in the aerospace and space industries due of their high specific strength and stiffness. [1]. Additionally, the use of fibre reinforced plastics is rising in the fields of automotive, medical, and general engineering since they open up new possibilities for product development and design. [2,3].

Although carbon fibre reinforced plastic (CFRP) components are typically produced close to net shape, they must be machined to create bore holes or notches in the workpiece and to enhance the quality of contact or functional surfaces. [4]. The process of machining is frequently carried out by milling, drilling, or grinding When compared to metallic alloys, CFRP's machining characteristics are fundamentally different, and the cutting mechanism is still mostly understood. [3,5,6,7,8]. The mechanical properties of the CFRP, which are influenced by the kind of fibre, the matrix material, the volume of the fibers, the orientation of the fibers, and the manufacturing method, have a significant impact on the machinability. It is challenging to identify relationships with broad applicability due to the abundance of affecting elements. Because CFRP is an inhomogeneous and anisotropic material, processing it can be challenging due to issues including fibre pull-out, delamination, and matrix material breakdown, which deteriorates the surface quality and material attributes. Thermal impacts have a significant impact on the mechanical characteristics of matrix materials in particular. [9]. In contrast, carbon fibres can withstand temperatures of up to 3000°C before the structure starts to degrade In the present study an up-cut milling process of unidirectional CFRP is investigated. Finding a link between the cutting conditions and parameters and the surface integrity of the milled workpiece is the goal of this study. As a result, the workpiece temperature, cutting speed, and fibre orientation have all been adjusted. Cross-sectional micrographs of the specimen are analysed to find probable damages at the machined surface.

2. Experimental procedure

Conducted milling experiments on CFRP using different types of solid carbide endmills with varying coatings (DLC coating, AlCrN coating, and uncoated). As per Figure.2.0 Milling was carried out on a three-axis CNC machine BFW make BMV 40 model using a solid carbide rougher endmill with an 18mm cutting diameter as per shown in Fig 3.0 The CFRP specimens were clamped on a Precision modular vice, and the endmill cutter was clamped in a BT40 Collet Chuck Holder. The size of the CFRP specimen was 125 x 125 x 30 mm, and machined a slot into the specimens under dry conditions. To investigate the milling process, varied the spindle speed (rpm), feed rate (mm/min), and depth of cut (mm) .The choice of coatings, spindle speed, feed rate, and depth of cut are crucial factors that can influence cutting forces,surface finish, and overall machinability of CFRP. The DLC (Diamond-Like Carbon) coating is known for its hardness and low friction properties, which can be beneficial for machining abrasive materials like CFRP. The AlCrN (Aluminum Chromium Nitride) coating provides high-temperature resistance and can extend the tool life in high-speed machining.The use of a modular vice and BT40 Collet Chuck Holder suggests that you employed a rigid setup, which is essential for stable machining and accurate results. Additionally, carrying out the experiments under dry conditions means that no coolants or lubricants were used during the milling process. Overall, the data collected from the experiments, including cutting forces, surface roughness, will provide valuable insights into the optimal machining parameters and the performance of different types of solid carbide endmills with varying coatings when milling CFRP. These findings can help optimize the milling process and enhance the productivity and quality of CFRP machining.



1) Solid Carbide End mill , 2) CFRP Material,3) Milling Tool Dynamometer , 4) Precision Modular Vice,5) BT40 Collet Chuck Holder

Fig. 2. Experimental setup used for miling CFRP

Figure 3

Test Table 1.0 (Using DLC Coated End mill)

SPEED (rpm)	FEED RATE (mm/min)	Depth of Cut (mm)	Cutting Force(Fx) (kgf)	Cutting Force(F_Y) (kgf)	Cutting Force(F_Z) (kgf)
1500	250	0.2	0	0	2.5
1500	250	0.35	0	0	3
1500	250	0.5	1	1	3.5
2575	350	0.2	0	0	2
2575	350	0.35	0.5	0.5	3
2575	350	0.5	0.5	0.5	3
4000	450	0.2	1	0	2
4000	450	0.35	1	0.5	2.5
4000	450	0.5	1	0.5	1

Test Table 2.0 (Using ALCRN Coated End mill)

SPEED (rpm)	FEED RATE (mm/min)	Depth of Cut (mm)	Cutting Force(Fx) (kgf)	Cutting Force(F_Y) (kgf)	Cutting Force(F_Z) (kgf)
1500	250	0.2	0	0	0
1500	250	0.35	0	0	0.5
1500	250	0.5	0	0	1
2575	350	0.2	0	0	1
2575	350	0.35	0	0	1
2575	350	0.5	0	0	1
4000	450	0.2	0	0	1
4000	450	0.35	0	0	1
4000	450	0.5	0	0	1

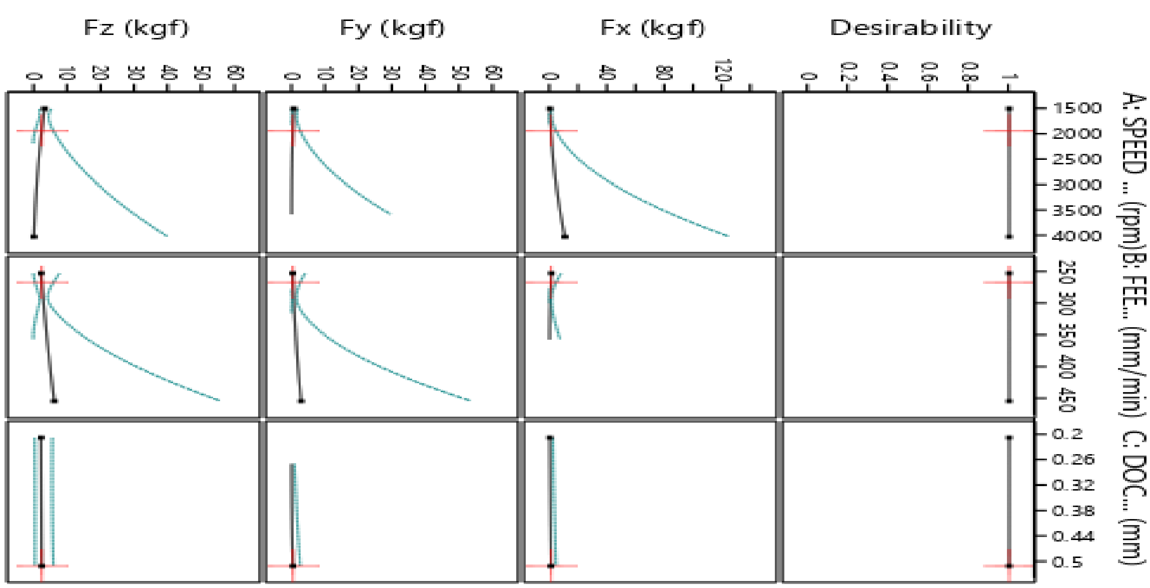
Test Table 3.0 (Using Un Coated End mill)

SPEED (rpm)	FEED RATE (mm/min)	Depth of Cut (mm)	Cutting Force(Fx) (kgf)	Cutting Force(F_Y) (kgf)	Cutting Force(F_Z) (kgf)
1500	250	0.2	0	0	0.5
1500	250	0.35	0	0.5	1
1500	250	0.5	0	0	0.5
2575	350	0.2	0	0	0.5
2575	350	0.35	0	0	0.5
2575	350	0.5	0	0	0.5
4000	450	0.2	0	0	0.5
4000	450	0.35	0	0	0.5
4000	450	0.5	0	0	0.5

3. Results and discussion

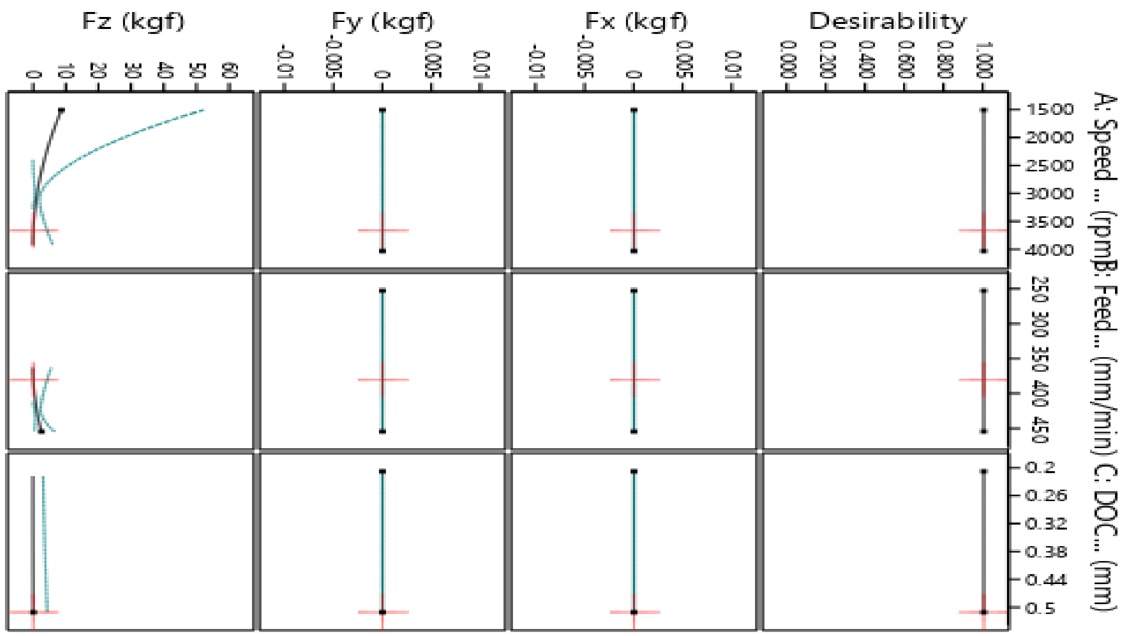
a) Influence of milling parameter on the Cutting Force by using DLC coated end mill

Cutting Force (Fx) and Cutting Force (Fy) vary with the depth of cut and feed rate, but they are generally low, often close to zero. This indicates that the cutting forces acting in the horizontal (Fx) and vertical (Fy) directions are minimal or negligible for the given cutting conditions and DLC-coated endmill. Cutting Force (Fz) increases with the depth of cut and feed rate. This is expected as a higher depth of cut and feed rate would result in more material being removed, requiring higher force to overcome the resistance during milling.The cutting force (Fz) is higher at higher spindle speeds (rpm). This is also expected, as higher spindle speeds lead to a higher number of cutting tool rotations per minute, resulting in more frequent contact between the tool and the material, thus increasing the cutting force.The DLC-coated endmill seems to provide consistent cutting performance throughout the tested cutting conditions, with relatively low cutting forces in both the horizontal and vertical directions.



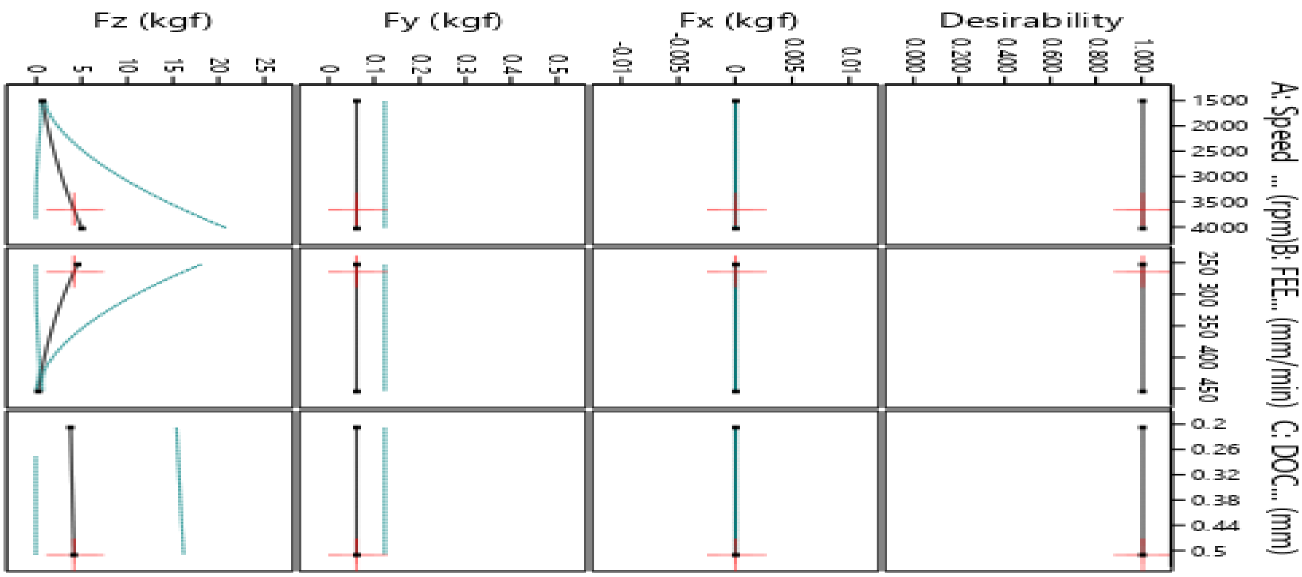
b***) b. Influence of milling parameter on the Cutting Force by using ALCRN coated end mill***

Cutting Force (Fx), Cutting Force (Fy), and Cutting Force (Fz) are consistently low for all the tested cutting conditions and the ALCRN-coated endmill. This suggests that the ALCRN coating is providing a smooth cutting action with reduced cutting forces during CFRP milling. As the depth of cut and feed rate increase, the Cutting Force (Fz) increases. This is expected since a higher depth of cut and feed rate results in more material being removed, requiring higher force for material removal.For all the tested spindle speeds (rpm) (1500, 2575, and 4000), the Cutting Force (Fz) remains constant at 1 kgf, indicating that the ALCRN-coated endmill is providing consistent performance across different spindle speeds.Overall, the data suggests that the ALCRN-coated endmill is effective in reducing cutting forces during CFRP milling, resulting in a smoother machining process. The low cutting forces can help minimize the risk of delamination and surface damage in CFRP components and contribute to longer tool life.



c***) Influence of milling parameter on the Cutting Force by using Un coated end mill***

Cutting Force (Fx), Cutting Force (Fy), and Cutting Force (Fz) are consistently low for all the tested cutting conditions and the uncoated solid carbide endmill. This indicates that the uncoated endmill is providing a smooth cutting action with minimal cutting forces during CFRP milling.Cutting Force (Fz) remains constant at 0.5 kgf for all the tested spindle speeds (1500, 2575, and 4000) and depths of cut (0.2, 0.35, and 0.5 mm). This suggests that the uncoated endmill is providing consistent performance across different cutting conditions.Cutting Force (Fy) increases slightly with an increase in the depth of cut. This is expected, as a higher depth of cut would result in more material being removed, requiring a slightly higher force for material removal.



Conclusion:

The DLC-coated endmill stands out as the best performer in terms of reducing cutting forces during CFRP milling. It consistently provides lower cutting forces compared to the other coatings (uncoated and ALCRN) under various cutting conditions.The uncoated endmill performs reasonably well, with moderate cutting forces. While not as low as DLC-coated, it remains a suitable option, especially considering cost considerations. The ALCRN-coated endmill shows higher cutting forces compared to DLC-coated, suggesting that it may not be as well-suited for low-force milling in CFRP.

The DLC-coated endmill demonstrates superior performance by providing lower cutting forces in CFRP milling compared to the uncoated and ALCRN-coated endmills. However, the uncoated endmill can still be an acceptable option for certain applications, especially when cost-effectiveness is a priority. The ALCRN-coated endmill may not be as favorable for low-force machining in CFRP based on the provided data.

References

[1] Brinksmeier, E.; Fangmann, S.; Rentsch, R.: Drilling of compositesand resulting surface integrity. CIRP Annals - Manufacturing Technology, Vol. 60, 2011, P. 57–60.

[2] Chang, C-S: Turning of glass–fiber reinforced plastics materialswith chamfered main cutting edge carbide tools. Journal of Materials Processing Technology, Vol. 180, 2006, P.117–129.

[3] Teti, R.: Machining of Composite Materials CIRP Annals –Manufacturing Technology, Vol. 51, 2002, P.611-634.

[4] V. Schulze, C. Becke, R. Pabst: Specific machining forces and resultant force vectors for machining of reinforced plastics. CIRP Annals - Manufacturing Technology, Vol. 60, 2011, P. 69–72.

[5] Davim, J.P.; Reis, P.: Damage and dimensional precision on milling carbon fiber-reinforced plastics using design experiments.Journal of Materials Processing Tech., Vol. 160, 2005, P.160–167.

[6] Ferreira, J.R.; Coppini, N.L.; Miranda, G.W.A.: Machining optimisation in carbon fibre reinforced composite materials.Journal of Materials Processing Technology, Vol. 92, 1999,P.135-140.

[7] Hu, N.S.; Zhang, L.C.: Some observations in grinding unidirectional carbon fibre-reinforced plastics. Journal of Materials processing Technology Vol. 152, 2004, P.333–338.

[8] Bhatnagar, N.; Ramakrishnan, N.; Naik, N.; Komanduri, R.: On the machining of fiber reinforced plastic (FRP) composite laminates Int. J. Mach. Tools Manufact., Vol. 35, No. 5, 1995, P.701-716.

[9] Zheng, X.: Nonlinear Strain Rate Dependent Composite Model Journal of Aerospace Engineering, Vol. 21, 2006, P.140-151.

[10] Davim, J. P., & Reis, P. (2005). Damage and dimensional precision on milling carbon fiber-reinforced plastics using design experiments. *Journal of Materials Processing Technology*, *160*(2), 160–167. https://doi.org/10.1016/j.jmatprotec.2004.06.003

[11] Caggiano, A. (2018). Machining of fibre reinforced plastic composite materials. *Materials*, *11*(3). https://doi.org/10.3390/ma11030442

[12] Ema, S., & Davies, R. (1989). Cutting performance of end mills with different helix angles. *International Journal of Machine Tools and Manufacture*, *29*(2), 217–227. https://doi.org/10.1016/0890-6955(89)90033-3

[13] Ghafarizadeh, S., Lebrun, G., & Chatelain, J. F. (2016). Experimental investigation of the cutting temperature and surface quality during milling of unidirectional carbon fiber reinforced plastic. *Journal of Composite Materials*, *50*(8), 1059–1071. https://doi.org/10.1177/0021998315587131

[14] Gordon, S., & Hillery, M. T. (2003). A review of the cutting of composite materials. *Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications*, *217*(1), 35–45. https://doi.org/10.1177/146442070321700105

[15] Waqar, S., He, Y., Abbas, C. A., & Majeed, A. (2017). Optimization of cutting tool geometric parameters in milling of CFRP laminates. *ICCM International Conferences on Composite Materials*, *2017-Augus*(August), 20–25.

[16] Guru Neelakandan, S., Lakshmanan, A. R., & Lakshminarayanan, V. (2012). Study on machinability behaviour of Carbon Fibre Reinforced Plastics (CFRP) using PCD 1500 grade insert. *Advanced Materials Research*, *488–489*, 713–717. https://doi.org/10.4028/www.scientific.net/AMR.488-489.713

[17] Bayraktar, S., & Turgut, Y. (2016). Investigation of the cutting forces and surface roughness in milling carbon-fiber-reinforced polymer composite material. *Materiali in Tehnologije*, *50*(4), 591–600. https://doi.org/10.17222/mit.2015.199

[18] De Lacalle López, L. N., & Lamikiz, A. (2010). Milling of carbon fiber reinforced plastics. *Advanced Materials Research*, *83–86*, 49–55. https://doi.org/10.4028/www.scientific.net/AMR.83-86.49

[19] Ghafarizadeh, S. B., Chatelain, J. F., & Lebrun, G. (2013). Multi Axis Machining of High Performance Cfrp. *The 19Th International Conference on Composite Materials*.

[20] Hashish, M. (2013). Trimming of Cfrp Aircraft Components. *WJTA American Waterjet Conference*.

[21] An, S. O., Lee, E. S., & Noh, S. L. (1997). A study on the cutting characteristics of glass fiber reinforced plastics with respect to tool materials and geometries. *Journal of Materials Processing Technology*, *68*(1), 60–67. https://doi.org/10.1016/S0924-0136(96)02534-4

[22] El-Hofy, M. H., Soo, S. L., Aspinwall, D. K., Sim, W. M., Pearson, D., M'Saoubi, R., & Harden, P. (2017). Tool Temperature in Slotting of CFRP Composites. *Procedia Manufacturing*, *10*, 371–381. https://doi.org/10.1016/j.promfg.2017.07.007

[23] Chibane, H., Serra, R., & Leroy, R. (2017). Optimal milling conditions of aeronautical composite material under temperature, forces and vibration parameters. *Journal of Composite Materials*, *51*(24), 3453–3463. https://doi.org/10.1177/0021998316687626

[24] An, Q., Ming, W., Cai, X., & Chen, M. (2015). Effects of tool parameters on cutting force in orthogonal machining of T700/LT03A unidirectional carbon fiber reinforced polymer laminates. *Journal of Reinforced Plastics and Composites*, *34*(7), 591–602. https://doi.org/10.1177/0731684415577688

[25] Azmi, A. I. (2013). Chip formation studies in machining fibre reinforced polymer composites. *International Journal of Materials and Product Technology*, *46*(1), 32–46. https://doi.org/10.1504/IJMPT.2013.052790

[26] Chatelain, J. F., & Zaghbani, I. (2011). Effect of tool geometry special features on cutting forces of multilayered CFRP laminates. *International Conference on Manufacturing Engineering, Quality and Production Systems, MEQAPS - Proceedings*, 85–90.

[27] Sorrentino, L., & Turchetta, S. (2014). Cutting Forces in Milling of Carbon Fibre Reinforced Plastics. *International Journal of Manufacturing Engineering*, *2014*, 1–8. https://doi.org/10.1155/2014/439634

[28] Haddad, M., Zitoune, R., Eyma, F., & Castanie, B. (2014). Study of the surface defects and dust generated during trimming of CFRP: Influence of tool geometry, machining parameters and cutting speed range. *Composites Part A: Applied Science and Manufacturing*, *66*, 142–154. https://doi.org/10.1016/j.compositesa.2014.07.005

[29] Chen, T., Wang, D., Gao, F., & Liu, X. (2017). Experimental study on milling CFRP with staggered PCD cutter. *Applied Sciences (Switzerland)*, *7*(9). https://doi.org/10.3390/app7090934

[30] Çelik, Y. H., Kilickap, E., & Kilickap, A. İ. (2019). An experimental study on milling of natural fiber (jute)- reinforced polymer composites. *Journal of Composite Materials*, *53*(22), 3127–3137. https://doi.org/10.1177/0021998319826373

[31] Kiliçkap, E., Yardimeden, A., & Çelik, Y. H. (2015). Investigation of experimental study of end milling of CFRP composite. *Science and Engineering of Composite Materials*, *22*(1), 89–95. https://doi.org/10.1515/secm-2013-0143

[32] Nguyen-Dinh, N., Bouvet, C., & Zitoune, R. (2019). Influence of machining damage generated during trimming of CFRP composite on the compressive strength. *Journal of Composite Materials*. https://doi.org/10.1177/0021998319883335

[33] Slamani, M., Chatelain, J. F., & Hamedanianpour, H. (2019). Influence of machining parameters on surface quality during high speed edge trimming of carbon fiber reinforced polymers. *International Journal of Material Forming*, *12*(3), 331–353. https://doi.org/10.1007/s12289-018-1419-2