COB-2021-2233
ANALYSIS OF THE INFLUENCE OF MACHINE VIBRATION IN THE MILLING OF CARBON FIBER REINFORCED POLYMER (CFRP) LAMINATES

Wesley Soares Camargo
Gustavo Franco Barbosa
Departamento de Pós-graduação em Engenharia Mecânica (PPGEMec), Universidade Federal de São Carlos (UFSCar). Rodovia Washington Luís, km 235, São Carlos, CEP 13565-905, SP
wesleyscamargo@gmail.com
gustavofb@ufscar.br

Sidney Bruce Shiki
bruce@ufscar.br

Abstract. *The use of composite materials in the manufacture of products has grown in different sectors of the industry, which encourages research and development aimed at processing these materials. The machining conditions imposed in the manufacturing process of a material are determining factors in the final quality of the product, due to structural changes arising from cutting forces, vibrations and temperature, in addition to other interferences generated by the process in the surface finish of the machined part. Given these requirements, studies related to the influence of different machining conditions on the milling processes of a composite material becomes important. Thus, the research project in question proposes a comparative study through combinations, involving different types of machining parameters used in the milling process of parts in CFRP (Carbon Fiber Reinforced Polymer) laminates, so that SEM analyzes will be performed (Scanning Electron Microscopy) to verify the correlation between the integrity and quality of the surface finish of the carbon fiber laminate, related to the delamination conditions, caused by the different machining conditions imposed.*

Keywords: *Milling, CFRP, Delamination, Machine Vibrations, Surface finish.*

1. INTRODUCTION

In an increasingly competitive market, industries have been developing technologies and materials that allow them to optimize manufacturing processes and specific product design characteristics, such as mass and mechanical strength (Nikbakt *et al.*, 2018). This need generates advances such as the improvement of organic chemistry, development of resins for the most diverse applications and glass and aramid fibers, generating the competitiveness of composites as engineering materials for the most diverse applications (Martins, 2014).

Composite materials can be defined with an assembly of two or more materials or components, so that the final properties are superior or more efficient than their constituents if evaluated separately, meeting the needs of high performance in their mechanical and thermal characteristics (Hsissou *et al.*, 2021).

The CFRP (Carbon Fiber Reinforced Polymer) laminates, even though they are manufactured under the concept of near net shape technology, that is, very close to their final shape, still demand the need for machining processes such as milling to achieve the desired final geometry (Sheikh-Ahmad, 2009), ensuring that the final part conforms to product design requirements.

This type of material is manufactured by assembling a specific series of layers of a specific material and the orientation of the layers can be varied or not. According to Figure 1, on the left a unidirectional structure is presented where all the layers of the composite material are directed at 0º (the same direction), and the stiffness resistance is only in the fiber direction, whereas on the right a structure is presented almost isotropic, where the layers are oriented by varying the direction of the material layers, in this type of configuration the stiffness resistance is in both directions (Rana and Fangueiro, 2016).

In the machining process, one of the widely used resources is lateral or edge milling, in which the machining conditions imposed in the manufacturing process of a material are determining factors in the final quality of the product (Groover, 2019), due to structural changes arising from cutting forces, vibrations and temperature, as well as other interferences generated by the process in the surface finish of the machined part. Given these requirements, studies related to the influence of different machining conditions on the milling processes of a composite material become important to identify

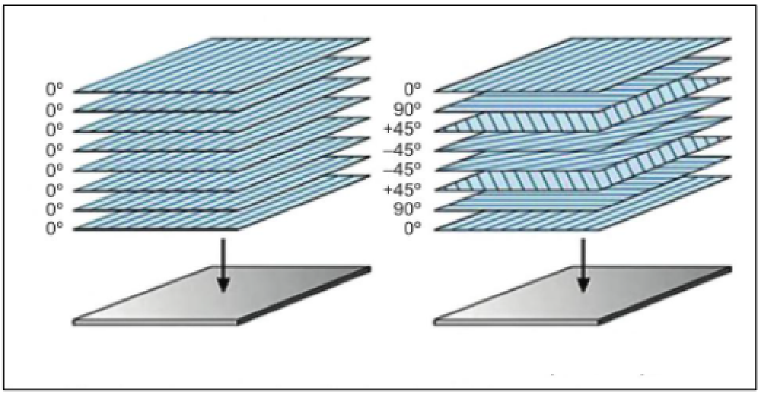

Figure 1. Schematic representation of laminated composites.

the complications that generate delamination, which is one of the most severe non-conformities present in the machined surface of CFRP.

(Wang *et al.*, 2016) From different machining parameters used in their tests, they related the increase in cutting temperature with different orientation angles of the CFRP carbon fiber, and concluded that the intensity of the cutting force decreases with increasing of the orientation angle of the carbon fiber and, consequently, the machining temperature also reduces, being the orientation angle of 45° which generates less heat in the system.

(Chen *et al.*, 2017) studied the effects of wear of the PCD (Poly-Crystalline Diamond) tool on the CFRP machined surface comparing the data with two different types of cutting tools, using a step cutter and a tooth cutter straight. They concluded that defects on the machined surface occur first and most severely in the region where the carbon fiber is oriented at 90º and 0º and that they worsen and expand to other fiber orientations as the tool wears out. They also concluded that the step cutter has better performance when compared to the straight tooth cutter, because its geometry presents an angle inclination both to the right and to the left, which makes the part withstand bidirectional cutting forces, thus inhibiting delamination effects and improving the conditions. of cutting.

(Liu *et al.*, 2017) through their studies on the development of a step cutter for CFRP machining, they identified through the regression model the influence of the cutting force on the milling process, reaching the conclusion that the cutting force decreases with increasing cutting speed and increases with increasing feed rate per tooth and width of the milling region.

Mechanical or machine vibration is an inherent characteristic of the milling and machining process in general, being caused by the dynamic interaction between the cutting tool and the part being machined, which can cause finishing problems on the machined surface, mechanical vibrations can be found in all types of machining and classified into three classes, free, forced and self excited. Free vibration occurs as a result of the collision between tool and workpiece so that the intensity of the amplitude is decreasing and the frequency is equal to the damped natural frequency. Cutter teeth in contact with the machined surface with constant amplitude and vibration frequency equal to the excitation frequency of the force. The self-excited vibration is a result of the part-cutting tool interaction due to the contact between the cutting tool with a surface. previously machined. These interactions can lead to unstable dynamics of the cutting process caused by the feedback of the machining process (Muhammad *et al.*, 2017).

Delamination is a characteristic of non-compliance presented during lateral milling of composite materials, where the heterogeneous structure of the material makes the machining process extremely difficult (Chouhan *et al.*, 2016), being of great importance in manufacturing engineering in general to understand how to delamination is formed in the (Colligan *et al.*, 1992) milling process. (Chen *et al.*, 2019) established in their studies a direct relationship between the wear of the rhombic cutter coating monitored by a microscope and the quality of the machined surface monitored by (MEV), showing that there are two stages of tool coating wear, where the Initial wear of the coating implies an acceptable surface quality, as the tool is still capable of shearing the fibers from the material, whereas wear due to shedding of the coating ends up compressing and extruding the fibers during milling, which significantly worsens the quality of the machined surface , generating delamination. (Ozkan *et al.*, 2020) concluded in their studies that the cutting parameter that most influences the emergence and intensity of delamination is the advancement rate.

2. EXPERIMENTAL PROCEDURE

This chapter presents the methodology used for testing materials considering the machine tool used, the fixation system and the machining of the specimen; the data acquisition system and the analysis and characterization of the machined surface.

2.1 Machine-tool

The milling of the specimen will be done in a CNC machining center Romi D800 maximum power of 18.5 KW and maximum rotation of 10,000 RPM, the specimen clamping system will be done by means of a clamped vise jig on the machining table with clamping clamps, for correct positioning of the vise template, it will be positioned with the aid of a dial indicator to square the position according to the machining head (Figure 2).

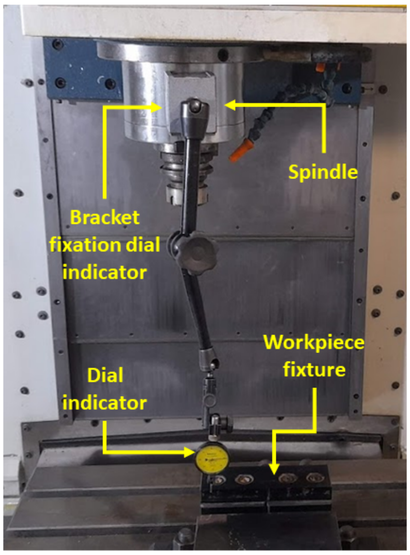

Figure 2. Walrus jig positioning.

2.2 Milling cutter

The machining process will be developed with a rotary file type router cutter with a 6.35mm diameter, diamond coated carbide, cutting length of 19mm and total tool length 50.8mm. The tool supplier is the company OSG Sulamericana . Figure 3 shows the design of the cutter to be used.

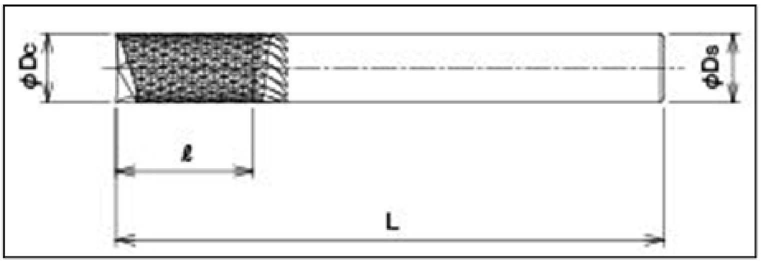

Figure 3. Milling cutter.

2.3 Specimen

The test specimen tested is a CFRP laminate with 3mm thick, 50mm wide and 50mm long (Figura 4), the laminate is made of epoxy resin and carbon fiber fabric type 2x2 twill and 3k yarn, varying the orientation of the tissue layers at 0º and 90º, Table 1, presents the physical and mechanical properties of the material used in the test.

2.4 Machining parameters

During the machining process of the specimen, the cutting parameters referring to cutting speed and RPM will be constant, while the feed rate will be varied in three different intensities during milling. Table 2 presents the detailed data of the cutting parameters used in each of the specimen.

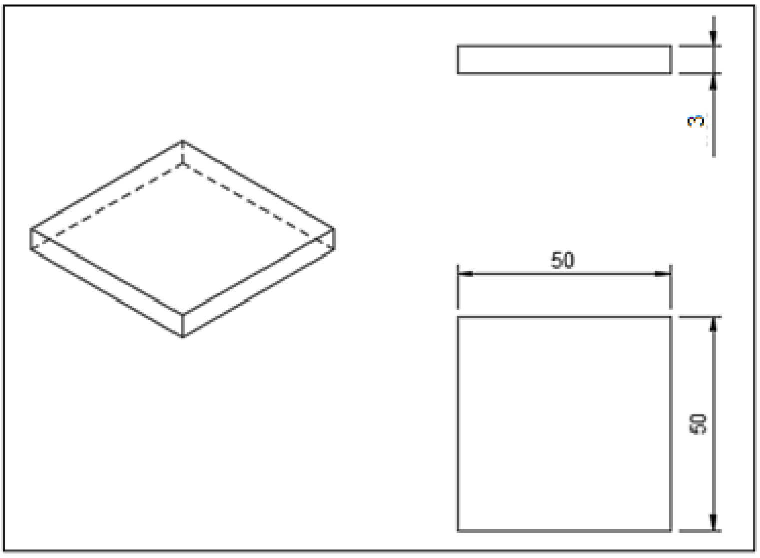

Figure 4. Specimen drawing.

Table 1. Physical and mechanical properties of the specimen.

	Tensile Strength	Traction Module	Specific weight
Unit	MPa	GPa	g/cm³
Value	350	40	1.50
Standard	ASTM D-638	ASTM D-638	ASTM D-792

Table 2. Machining parameters.

Specimen	Vc (m/min)	n (RPM)	Vf (mm/min)
1	100	5015	500
2	100	5015	600
3	100	5015	700

2.5 Data acquisition system

During the milling process, mechanical vibration signals from the machine tool set were captured with a MEMS ADXL335 triaxial accelerometer (sensitivity: 300 mV / g, frequency range up to 1.6kHz), attached to the specimen. The accelerometer was connected to an Arduino MEGA 2560 board, which through a code via the Arduino IDE interface manages data acquisition for a period of 5 seconds. The data collected during the specimen machining process were saved in an Excel spreadsheet and then evaluated via MATLAB software. Figure 5 presents the schematic diagram of the acquisition and analysis of vibration data.

2.6 Machined surface analysis

The analysis of the machined surface was performed using a scanning electron microscope (SEM), brand JEOL, model JSM-7500F, with PC-SEM v 2,1,0,3 operating software. equipped with secondary electron detectors, backscattered and chemical analysis (energy dispersive spectroscopy - EDS) by Thermo Scientific brand, Ultra Dry model, with NSS 2.3 operating software.

3. RESULTS AND DISCUSSION

The mechanical vibration data sampled during the experimental procedure are used to analyze the dynamic behavior occurred and guide this study, Figure 6 shows the vibration values in g on the Z axis, considering three different values for the feedrate, being possible to identify a system response when changing the machining parameter under study, in this case the feedrate. For each feed rate tested, the system demonstrated a specific response with different intensities of the sampled signals.

The analysis in the frequency domain from the signal power spectral density (Figure 7) shows the variation of amplitudes in relation to the frequencies present in the system, commonly in the presented graphs, it is possible to verify,

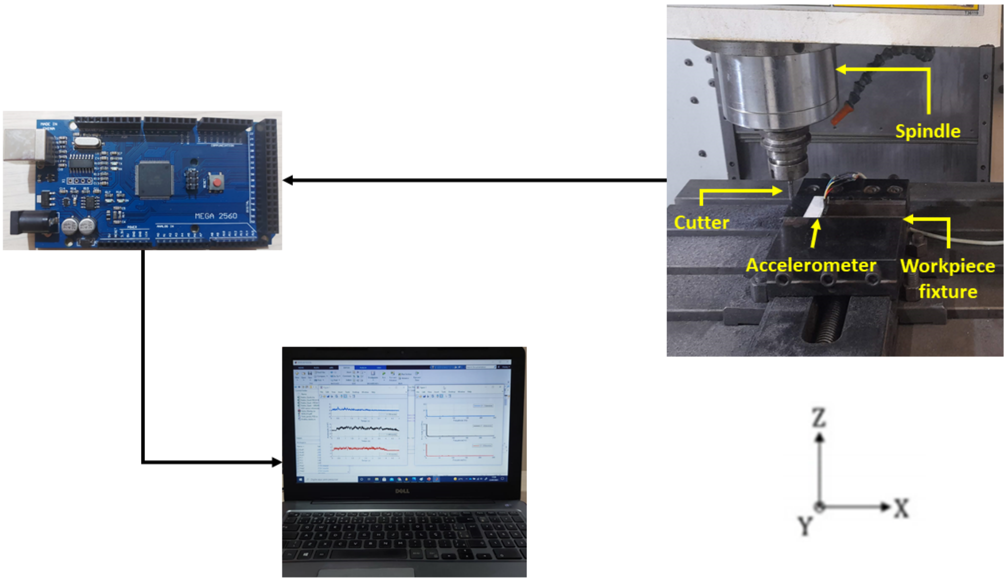

Figure 5. Schematic diagram of the milling process.

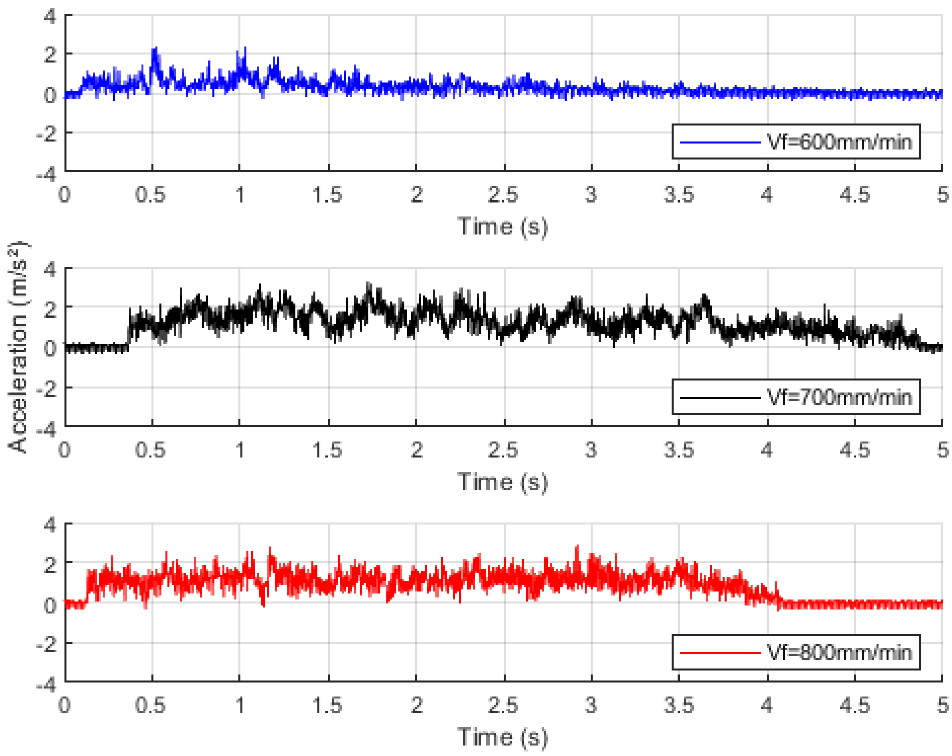

Figure 6. Acceleration signals collected during the experiments.

highlighted with values. Commonly in the three collected signals, it is possible to verify a first frequency of approximately 60 Hz, which allows us to conclude that this is the frequency of the electrical network. The presence of the harmonic rotation frequency of the machining spindle being 5015 RPM, is evidenced in the three collected signals, being approximately 84 Hz and approximately 120 Hz. In view of the analysis of the collected data, it is possible to guarantee the efficiency of the data acquisition system, and it was possible to identify the network frequency and the harmonics of the rotation of the RPM used.

The SEM analysis allowed verifying the characteristic of the machined surface in each of the different machining

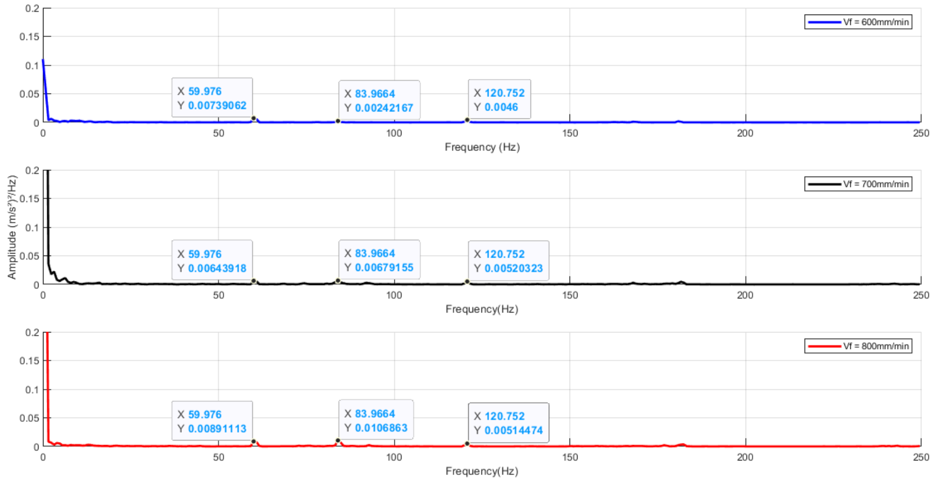

Figure 7. Power spectral density of collected signals.

conditions imposed on the system, Figure 8, where, a, b and c are respectively the images referring to the feedrates of 600, 700 and 800 mm/min. According to the acquired images, it is possible to correlate the different machining parameters adopted with the respective quality of the surface finish of the machined parts. The feedrate parameter of 800 mm/min proved to be the most efficient, as it is possible to verify in Figure 8 c, a surface finish with machining imperfections much smaller than that observed in the other two images.

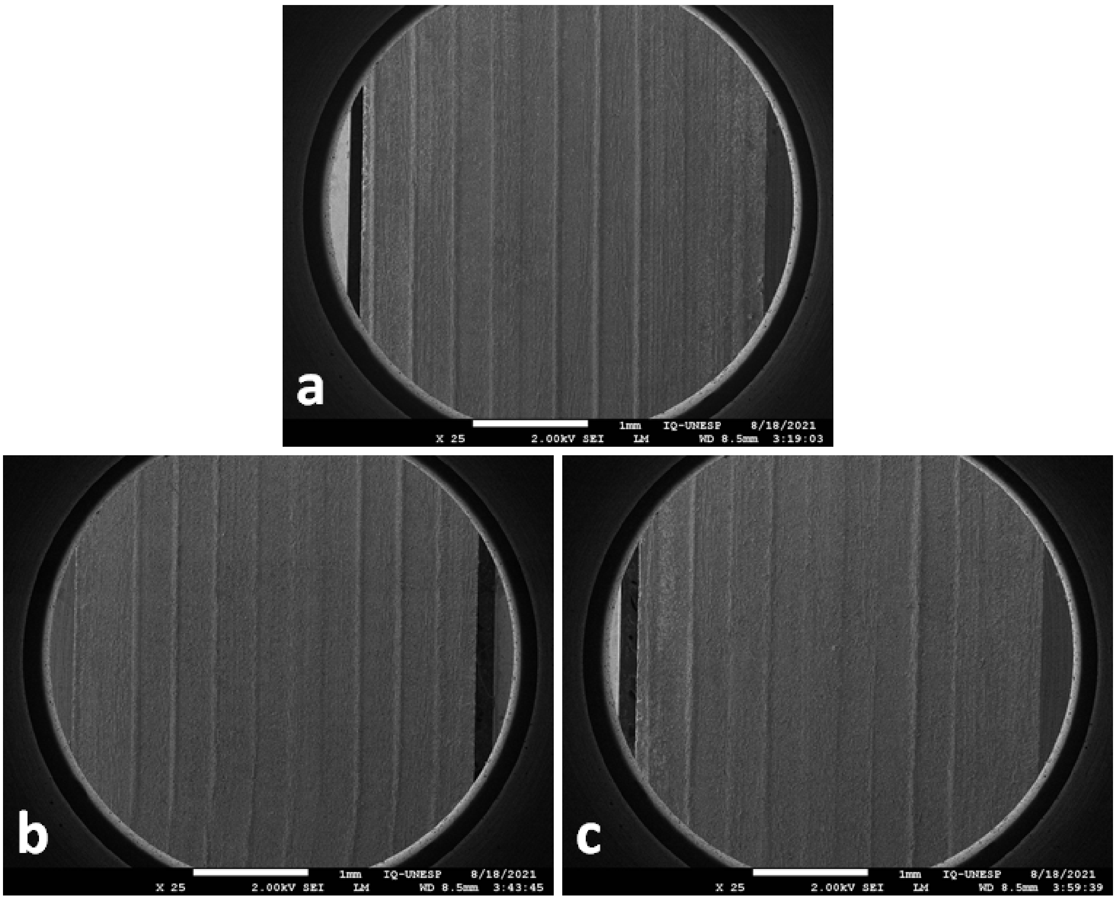

Figure 8. SEM's Images.

4. CONCLUSIONS

The experiment showed that there is a correlation between the machining advance, the mechanical vibration of the machine tool set, with regard to the quality of the machining surface finish of the CFRP laminate used in machining tests, making it clear that higher feed rates impose on the system features that favor the machining process. The experiment also made it possible to collect data in real time, together with a data acquisition system, allowing developments and studies of the composites machining process, which guarantees for the scientific community, subsidies for future studies and improvements in the machining process of composites considering as input parameters, the mechanical vibration and output parameters, the quality of the surface finish of the machined part.

5. ACKNOWLEDGEMENTS

To UFSCar for the opportunity to develop this project together with the Graduate Program in Mechanical Engineering (PPGMec).

To the members and coordinators of the CCDPN and LIEC groups.

6. REFERENCES

Chen, T., Wang, D., Gao, F. and Liu, X., 2017. "Experimental study on milling cfrp with staggered pcd cutter". *Applied Sciences*, Vol. 7, No. 9, p. 934.

Chen, T., Xiang, J., Gao, F., Liu, X. and Liu, G., 2019. "Study on cutting performance of diamond-coated rhombic milling cutter in machining carbon fiber composites". *The International Journal of Advanced Manufacturing Technology*, Vol. 103, No. 9, pp. 4731–4737.

Chouhan, H., Singh, D., Parmar, V., Kalyanasundaram, D. and Bhatnagar, N., 2016. "Laser machining of kevlar fiber reinforced laminates–effect of polyetherimide versus polypropylene matrix". *Composites Science and Technology*, Vol. 134, pp. 267–274.

Colligan, K., Ramulu, M. *et al.*, 1992. "The effect of edge trimming on composite surface plies". *Manufacturing Review(USA)*, Vol. 5, No. 4, pp. 274–283.

Groover, M.P., 2019. *Introdução aos processos de fabricação*. Grupo Gen-LTC.

Hsissou, R., Seghiri, R., Benzekri, Z., Hilali, M., Rafik, M. and Elharfi, A., 2021. "Polymer composite materials: A comprehensive review". *Composite Structures*, Vol. 262, p. 113640.

Liu, G., Qian, X., Chen, H., Gao, F. and Chen, T., 2017. "Development of a staggered pcd end mill for carbon fiber reinforced plastic". *Applied Sciences*, Vol. 7, No. 3, p. 245.

Martins, F.R., 2014. *Caracterização do fresamento de chapas de compósito polímero reforçado com fibras de carbono (PRFC)*. Ph.D. thesis, Universidade Estadual de Campinas, Faculdade de Engenharia Mecânica, Campinas, SP, Campinas, Brasil.

Muhammad, B.B., Wan, M., Feng, J. and Zhang, W.H., 2017. "Dynamic damping of machining vibration: a review". *The International Journal of Advanced Manufacturing Technology*, Vol. 89, No. 9-12, pp. 2935–2952.

Nikbakt, S., Kamarian, S. and Shakeri, M., 2018. "A review on optimization of composite structures part i: Laminated composites". *Composite Structures*, Vol. 195, pp. 158–185.

Ozkan, D., Panjan, P., Gok, M.S. and Karaoglanli, A.C., 2020. "Experimental study on tool wear and delamination in milling cfrps with tialn-and tin-coated tools". *Coatings*, Vol. 10, No. 7, p. 623.

Rana, S. and Fangueiro, R., 2016. *Advanced composite materials for aerospace engineering: Processing, properties and applications*. Woodhead.

Sheikh-Ahmad, J.Y., 2009. *Machining of polymer composites*, Vol. 387355391. Springer.

Wang, H., Sun, J., Zhang, D., Guo, K. and Li, J., 2016. "The effect of cutting temperature in milling of carbon fiber reinforced polymer composites". *Composites Part A: Applied Science and Manufacturing*, Vol. 91, pp. 380–387.

7. RESPONSIBILITY NOTICE