Analysis of defects caused by drilling process under dry and cryogenic cooling conditions in pps-c and epx-c composite laminates

F. A. Toti[1], A. C. S. P., Tarpani[2], J. R. Tarpani[2]

[1]*Center Paula Souza, Faculty of Technology of Sorocaba, SP, Brazil*
[2]*University of São Paulo, Engineering school of São Carlos, SP, Brazil*
e-mail: ftoti@fatecsorocaba.edu.br

Abstract

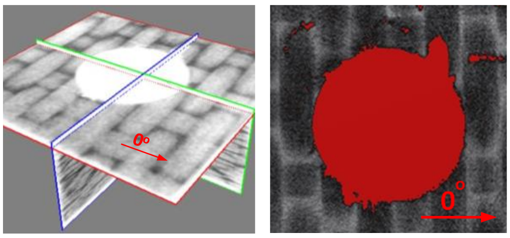
In the aeronautics, astronautics and sustainable energy industries, among others, the use of continuous carbon fiber reinforced thermoplastic and thermo-rigid matrix (CFRP) structural composite laminates is increasing, highlighting their excellent mechanical properties per unit mass. Components and structures designed and manufactured with these laminates are almost entirely drilled, so this aspect is of fundamental importance to guarantee their integrity and safety under operating conditions. The objective of this work is to evaluate and correlate the defects caused by the drilling process in PPS-C and EPX-C laminates under dry and cryogenic cooling conditions, evaluating their performance and proposing a new global damage evaluation criterion.
Keywords: composite laminate; micro-CT; drilling; delamination

Introduction

In recent decades there has been a considerable increase in the study of drilling, as it is a promising area from the point of view of practical application and involves many process variables, being considered essential by industries using composite materials. Dry drilling is widely used as it does not require cutting fluids, however heat generation can lead to the occurrence of delamination defect in addition to tool wear. In order to minimize these problems, cryogenic cooling drilling is gaining increasing attention as it offers better conditions for reducing the cutting tool temperature than conventional cooling [1]. Several studies on drilling process under cooling conditions are found in the literature, proposing defect evaluation methods. They recently presented a general review of the most commonly used methodologies for assessing the extent of delamination defect, its mechanism and factors applied to direct their control in industry, concluding that it is still difficult to have a comprehensive assessment of the damaged area and delamination cracks [2].

Experimental Procedure

The specimens were extracted from the Phenomenon-Carbon-Sulphide (PPS-C) laminates supplied by Tencate® and from the Epoxy-Carbon (EPX-C) laminated by Hexcel®, according to the orientation of the web (0º) and warp (90º), with dimensions of 14mmx14mm and integral thickness of 5mm. In the drilling process a Romi D800 three axis machining center was used. The drilling was performed under dry conditions and under cryogenic cooling, with cutting speed (V_c) set at 60 m/min, with four different feeds (f) per rotation: 45, 90, 180 and 360 µm/rot. Through the acquisition of feed force versus tool displacement data, the computer program was developed using the Matlab educational platform R2015a educational software to evaluate the mechanical energy in the drilling process (E_{mp}). The 6mm diameter carbide drill bit with two 130º and 60º tip angles of A1163-6 diamond plating was supplied by Seco Tools Industry. The cooling system used to apply liquid nitrogen (LN_2) was the SC-18 model supplied by Semper Crio Industry. Then, techniques were applied to obtain images that were treated and analyzed in 2D and 3D, using registered and public domain software to evaluate the defects. Subsequently, the specimens will be sectioned for analysis by optical and scanning electron microscopy (SEM). Figure 1 shows images obtained by CNPEM micro-CT of the PPS-C composite laboratory drilled under cryogenic cooling, with advance (f) of 180 µm/rot.



(a) (b)

Figure 1- 3D sectioned images by DataViewer® software (a). 2D images handled by NIH software ImageJ (b).

Figure 2 shows a micro-CT image of the deep hole drilling with start of defect extension perpendicular to the feed force under dry condition with (f) 180 µm / rot of EPX-C composite.

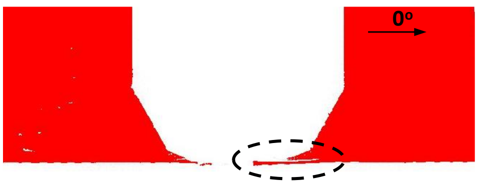


Figure 2 - 2D sectioned images treated by NIH software ImageJ.

Figure 3 shows the 3D assembly of the image slices containing the total volume of material removed in the process, as well as the volumes containing defects in and out of the specimen.

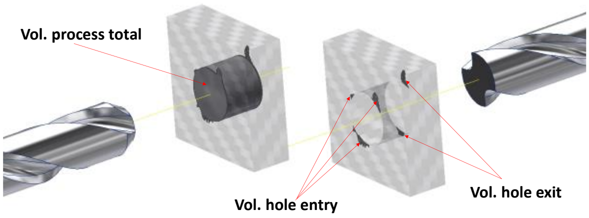


Figure 3 - 3D assembly of image slices by software CAD INVENTOR®.

Results and Discussion

Figure 4 shows the maximum bore outlet diameter (Dmax) values obtained under dry and cryogenic cooling conditions as a function of the feed rates (f) for the PPS-C and EPX-C composites. Note that the largest dimensional variation occurred at the smallest feed rate because the tool takes longer to drill the specimen, generating more heat in the dry condition and consequently the hole expansion. The same can be observed for the cryogenic condition, because the lower the advance, the longer is the cooling time and greater the hole retraction.

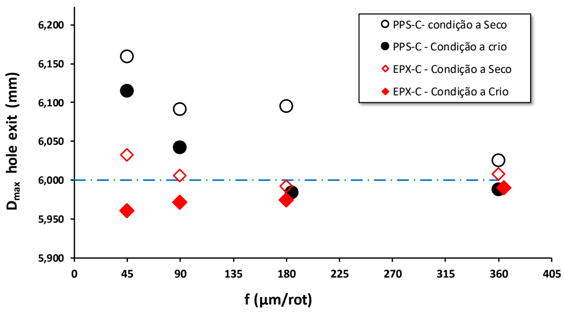


Figure 4 - D_{max} values versus advancements under dry and cryogenic cooling conditions for PPS-C and EPX-C composites.

Figure 5 shows the values of the volumes containing defects in the hole entry and exit versus the feed rates (f) under cryogenic cooling of the PPS-C composite. It is observed that in the advances of 180 and 360 µm/rot occurred inversion of the values between the volume at the exit and the volume in the entry compared to the advances of 45 and 90 µm/rot. This is due to the increase in feed which consequently increases the impact of the tool with the specimen input surface in the process. In the 45 and 90 µm/rot feeds, the volume values at the exit are higher than at the entry, in line with the literature that most defects are concentrated at the hole outlet in the drilling process for composites.

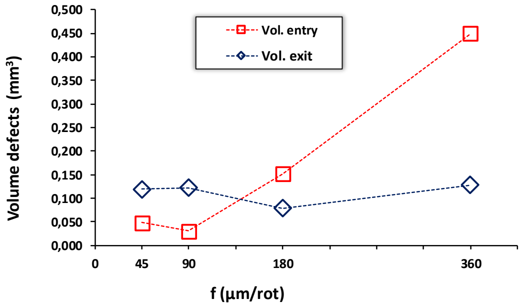


Figure 5 - Values of defects at hole entry and exit versus feeds for PPS-C composite.

Volume values containing hole exit defects when compared with the values of the conventional (F_d) and adjusted (F_{da}) two-dimensional delamination defect factors as proposed in the literature do not show the same trend, indicating that with further study, a new defect assessment criterion be defined. Figure 6 presents the values obtained from Fd and Fda as a function of the advances, with cryogenic cooling [3].

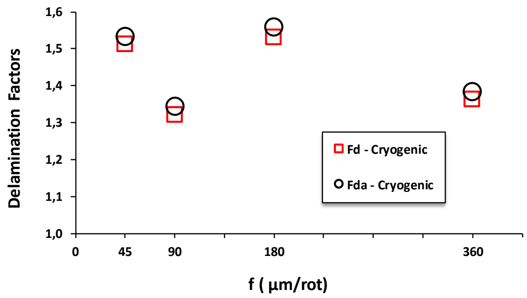


Figure 6 - F_d and F_{da} factors values at hole exit versus feed rate for PPS-C composite.

Conclusions

The present work in progress presented experimental results of the volumes containing defects in the entrance and exit of the hole, which will be correlated with the mechanical energy in the drilling process to define a new damage evaluation criterion. Through optical microscopy and scanning electron techniques confirm the depth and extent of the defects, as well as classify them by type. Finally, to evaluate the performance of the two composite laminates when submitted to dry process and under cryogenic cooling.

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References

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