TEMPERATURE EVALUATION IN CFRP DRILLING

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Abstract. *The objective of this work is to evaluate the temperature behavior on the surface during drilling the CFRP and to check for possible defects caused on the polymer matrix, due to the possibility of exceeding the matrix degradation temperature that can compromise the mechanical properties of the composites. The experiments were carried out with 2.4 mm thick CFRP plates and using constant feed during drilling, to determine the need to use cutting fluids (compressed air, cold air, Nitrogen, MQL) during drilling. Measurements were made both at the entrance and at the exit of the holes, first with a thermographic camera and later, for better verification, with Type T thermocouples installed on the side of the CFRP plates. The drilling process used constant cutting speed (Vc = 60m / min) and feed (f = 0.05mm / rot) and promoted longer tool contact time with the material. Cutting fluid was not used in the process. The drill used was 6mm. Among the results, high process temperatures above 180 ° C were not observed. The analysis of the surface aspect of the hole by SEM showed that there was no degradation of the matrix and the fibers did not present deformation.*

1. INTRODUCTION

The applications of carbon fiber-reinforced polymer (CFRP) have grown considerably due to the need for applications with high rigidity and resistance, low weight and good anti-corrosion properties [1]. Subsequent processes, such as machining, make it possible to assemble the components, with drilling being necessary for the installation of rivets and screws, as well as cuts, for openings, according to specific sizes (1). During the machining of composite materials, some problems can be highlighted, such as the rapid wear caused by fibers on tools, delamination, cracks, and thermal degradation of the matrix [1–3]. These defects interfere with the mechanical properties of the components, causing an increase in component rejections. Composites of fiber-reinforced polymeric matrix (FRP) are increasingly common alternatives to metals, especially in the aeronautical, naval, automotive and electronic industries, given the low weight combined with good mechanical resistance, low thermal and electrical conductivity [4].

The drilling of laminated composites with helical drills is susceptible to several types of defects classified in four main categories: (i) defects in the entrance of the hole, caused by the detachment of the fibers in the first layer of the plate by the main cutting edge of the drill, causing delamination . (ii) Defects in the hole exit, attributed to the stress caused by the feed force (F_f) in the last layers of the plate; when the tension exceeds the adhesion limit between fiber and matrix, cracks occur, which propagate, causing delamination. (iii) dimensional defects, which are a consequence of the variation of the fiber angle in relation to the cutting edge at the moment of shear - fibers cut at 90º undergo greater elastic deformation, reducing the final diameter of the hole in this direction. (iiii) thermal defects, originated from the friction between drill and part, and can affect the integrity of the polymer matrix, in addition to impairing the finish of the hole wall [5].

Regarding the defects associated with the drilling temperature of the CFRP, some studies have been carried out to ascertain this situation. Ramirez [6] evaluated the wear of MD cutting tools in CFRP drilling in order to correlate the wear with the damage of the tool, cutting forces, temperature and quality of the hole surface, focusing on the methodology for monitoring the temperature. He found that the increase in tool wear causes a gradual increase in the drilling temperature, impacting the topography / surface of the hole, affecting its quality and integrity.

Park et al. [7] demonstrated that carbon fibers can weaken the binder in cobalt grains, then splinters and fractures can occur at the cutting edges of tools, as well as temperature and cutting force increase the evolution of wear and interfere with the surface topography [1, 8], with abrasion being the main wear mechanism during drilling the CFRP [9]. Among the environmental agents that cause these failures are electromagnetic effects, atmospheric, electrical discharges, radiation, gases, and moisture absorption due to contact with organic liquids, such as lubricants, used in the manufacture of some elements. Thus, when the moisture absorption of the composite occurs, there is a shorter fatigue life for those reinforced by carbon fiber when compared to aramid composites, which are accelerated by the presence of holes [10].

For drilling of composite materials, the use of cooling lubricant is not recommended, due to the absorption of liquid by the material, as it results in a reduction in the fatigue life and the mechanical properties of the material, due to the lower adhesive forces between the matrix and fiber, leading to errors in shape and precision, not only in drilling, but in all material. However, the process carried out without lubricants results in higher drilling temperatures, which can generate thermal damage to the composite, due to the low thermal conductivity and the low expansion coefficient, causing precision errors in machining, as well as the possibility of reaching the degradation temperature. of the material (150 and 250 ° C) [11].

When the maximum temperatures are observed, they are associated with greater friction between the reinforcement layer, as they are no longer cut, but pressed. When low feed rates are used, a greater total contact length of the drilling tool and the part occurs, with greater friction between them, justifying the use of lower feed parameters for the experiment. Dry drilling can induce geometrical errors due to the possibility of heat accumulation in the cutting zone, due to the absence of lubricant coolants [10-12].

Conventional drilling, due to the limited access to the cutting zone to reduce temperatures, can generate a temperature above the glass transition temperature (160 ° C to 200 ° C), reducing the matrix hardness and consequent thermal degradation [12– 15], compromising the mechanical properties. The greatest impact occurs at the exit of the holes, due to its high susceptibility to damage from delamination, chipping and burrs, introducing great challenges for the generation of a qualified cut for the CFRP [16–18]. The CFRP manufacturing processes, such as stacking prepregs or bundles of fibers in different directions, result in anisotropic structures, as well as different thermal conductivities when comparing the reinforcements and the matrix, with cutting temperature associated with the direction of the fibers. of the composite [19–22].

In relation to the temperature monitoring process, verification via contact, by thermocouples and sensors are the most common, often using them only in drills, but in other cases, applying them in drills and materials, trying to cover the entire the periphery of the holes [6, 14–16, 22]. Some researchers use infrared thermography to perform these analyzes, due to the ability to verify a large detection area, concentrating on the analyzes at the drill outlet, where the characteristics of uncut area, cutting tool and chips still need better analysis. . Thermogravimetric analyzes allow the evaluation of the thermal stability of different laminates and the maximum temperatures of thermal cycling, thus determining the temperature of onset of degradation and the residual mass of the samples [23].

Brinksheimer et al. [24] found that conventional CFRP drilling reached low temperatures, not thermally degrading the material. The analysis was complemented by comparing with orbital drilling, which obtained lower temperatures when compared to conventional drilling. The observed temperature was between 80 ° C and 150 ° C, using 16mm drills, between different levels of cutting speed. Fu [14] mapped the temperature at the drill outlet during drilling the CFRP using infrared thermography and identified some important factors, such as the maximum temperature observed at the edges of the hole, related to the higher cutting speed and, consequently, the higher level temperature, facilitating the cutting of the material, observing temperatures around 160 ° C for the region close to the edge.

Weinert et al. [11] drilled composites reinforced with carbon fibers and reached temperatures between 100 and 180 ° C. The drilling was carried out with 8mm drills and 0.1mm / rev advance and the temperatures measured in the drill. The material reaches temperatures lower than those indicated by the drills. Ben et al. [16] studied the drilling temperature observed at the exit of CFRP holes, indicating a critical temperature for the degradation and initiation of failures associated with the 186 ° C material, as well as the degradation of the holes at the exit was high due to the increase in temperature , generating fragmentation in this region, high porosity, extraction of fibers and transversal cracks. In this experiment, samples were used with a thickness of 5mm, and cutting parameters of 9000 rpm and 25 mm / min. Among the conclusions, the great impact generated by the increase in temperature on the quality of the perforated surface was observed.

Due to all these characteristics, this work aims to evaluate the temperature in the CFRP drilling process and to observe defects, such as thermal degradation, which may compromise the use of materials in their applications. Thus, it is possible to define the need to use some means of cooling so that the material is not compromised.

2. MATERIALS AND METHODS

Data acquisition was performed using an HP Agilent 34970A Datalogger and the thermocouple used was Type R, with 0.5mm with a measurement range between 0 ° C and 1450 ° C with Platinum with 13% Rhodium and an error range of 0, 25% or 1.5 ° C and applied to environments with inert or oxidizing atmospheres and sensitivity of 12 µv / ° C.

The drills used are helical metal carbide Model H10NM series corodrill 860 with cross edging and Ø6 mm and DIALUB coating (DLC), total length 66 mm (28 mm of useful length). Helix angle φ= 16.6 ° Tip angle σ = 130 °. To measure the runout (δ), the Digimess dial indicator model 121.304 with a resolution of 10 µm was used.

The distance between the center of the holes was 20mm. Temperature monitoring was performed at the entrance and exit of the holes. Before the beginning of drilling, the drill runout (δ), all of which were below 0.001 mm. At the end, a comparison of temperatures was carried out, over several distances from the surface of the hole to the measurement point, evaluating the temperature obtained. Subsequently, the fibers and matrix were observed, via SEM and optical microscope, to verify burns, cracks and other flaws associated with drilling. The drill was analyzed to check possible wear and adhesions on the material.

The thermogravimetric analysis (TGA) for the evaluation of the thermal degradation temperature of the CFRP was analyzed at LAPOL, with a TGA Q50 V20.13 Build 39 device with a heating ramp of 20 ° C / min and a nitrogen atmosphere.

The cutting parameters used were constant feed (f = 0.05mm / rot) and constant cutting speed (vc = 60m / min). We chose to use this feed rate value (f) so that the contact time between the tool edges and the CFRP was as long as possible, in addition to being the lowest feed rate values indicated for the drilling of composite materials by the tool manufacturer.

The CFRP plate is made up of sheets manufactured with pre-impregnated carbon fiber fabric, having 10 layers, totaling 2.4mm. In the usable area, 20mm from the sides are disregarded, due to some losses and irregularities of material in this region, where the resin is not uniform. The plates were fixed using a wooden base, with a central opening, fixed to the tool holder, making it possible to control the tool advance with this fixation, as well as the plate temperature measurement in Fig. 1. In this experiment, the temperature of the drill was not measured, because the experimental apparatus is not appropriate for this situation. The measurement points were inserted at distances between 0.5mm and 1mm from the side of the holes, both at the entrance and at the exit of the holes.

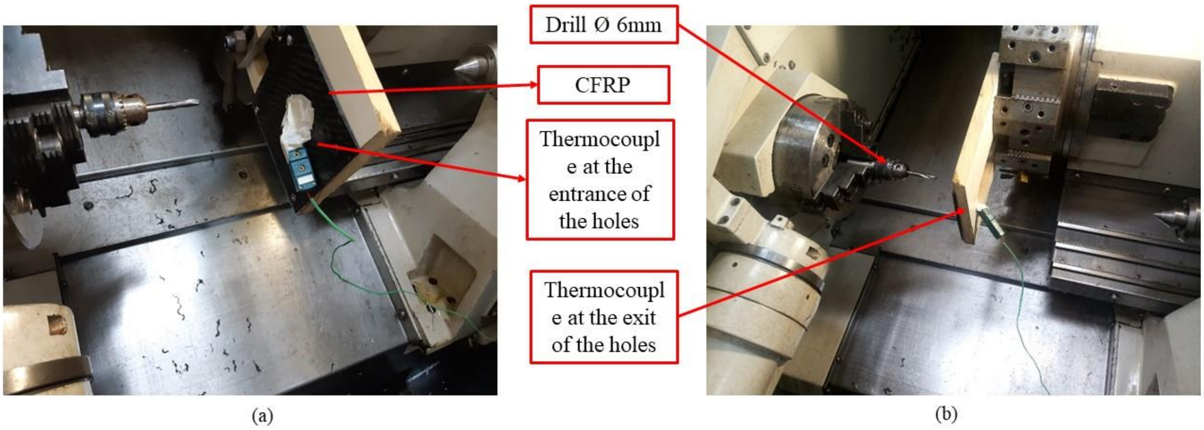


Figure 1 - Experimental setup: (a) diagram of mounting the plate on the vise and positioning of the thermocouple at the entrance of the plate; (b) positioning the drill and positioning the thermocouple at the exit of the plate.

3. RESULTS AND DISCUSSIONS

Temperature measurements can be seen in Fig. 2 for the various measurement points, with distances between the hole surface and the thermocouple established. For the measurement point of hole 1, with a distance of 0.8 mm from the thermocouple in relation to the surface of the hole, a maximum temperature of 35.2 ° C was reached, reaching the peak after 100mS after the drilling process started. For hole 2, the distance between the hole surface and the thermocouple is 0.9mm, reaching max. 35.918 ° C. In hole 3, the distance between the hole surface and the thermocouple is 35.735 ° C. For hole 4, at a distance of 0.5 mm from the surface of the hole and the thermocouple reached 49.204 ° C, which demonstrates the coherence between the increase in temperature and the decrease in the distance between the thermocouple and the surface of the holes.

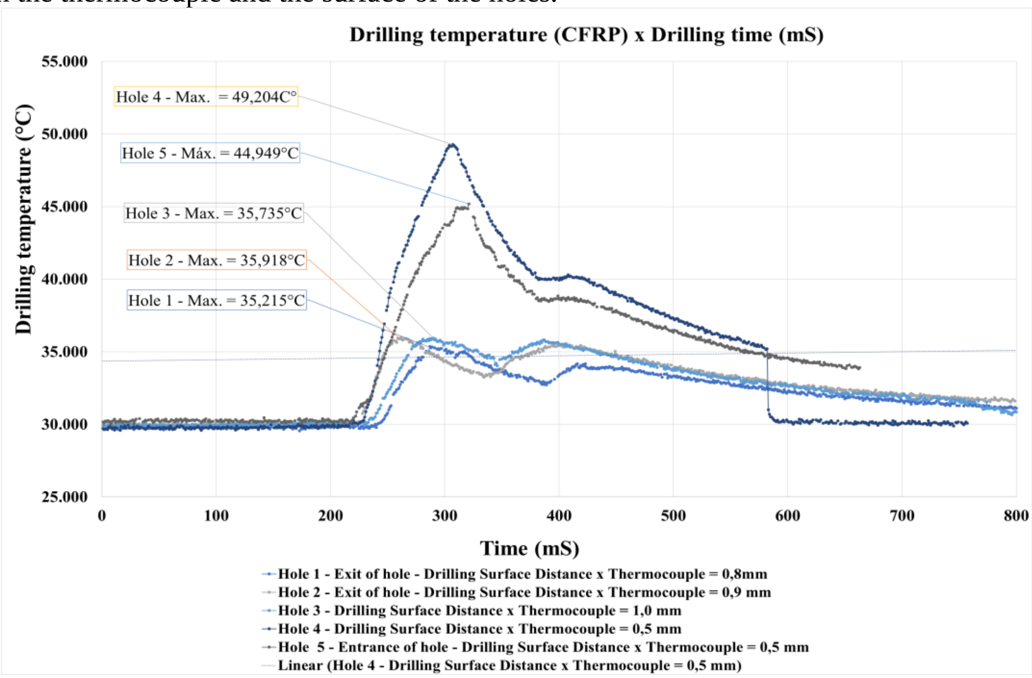


Figure 2 – Temperature drilling in CFRP.

In hole 5, where the temperature was measured at the entrance of the hole, with a distance between the surface of the hole and the thermocouple of 0.5 mm, the maximum temperature being 44.9 ° C, being lower compared to the temperature of hole 4, at the outlet, being smaller compared to that observed by Fu [14], who observed temperatures close to 200 ° C, highlighting this point as essential in the monitoring and monitoring of the region. This can be associated with the drill used as well as the monitoring system, by infrared, which can obtain the values instantly in the region of the output. The temperatures at the entrance of the hole are below the temperatures observed by [11, 24] both experiments carried out with drills of larger diameter and faster cutting speeds, causing greater friction between the drill and the surface, increasing the drilling temperature.

The thermogravimetric analysis (TGA) and those derived from the thermogravimetric curves (DTGs) obtained from the CFRP samples observe the temperature of onset of mass reduction of approximately 350 ° C of the sample reaching the peak of degradation in the range of 450 ° C, values distant from the temperatures reached in the experiments in Fig. 3. The results were close to the TGA values obtained by Turki [18] who analyzed the TGA of the CFRP and observing the impact of the temperature of the ultrasound-assisted drilling process. In this experiment, the author compared the temperature reached by the conventional drilling process (max. 90.1 ° C), lower than the start of the degradation of the CFRP.

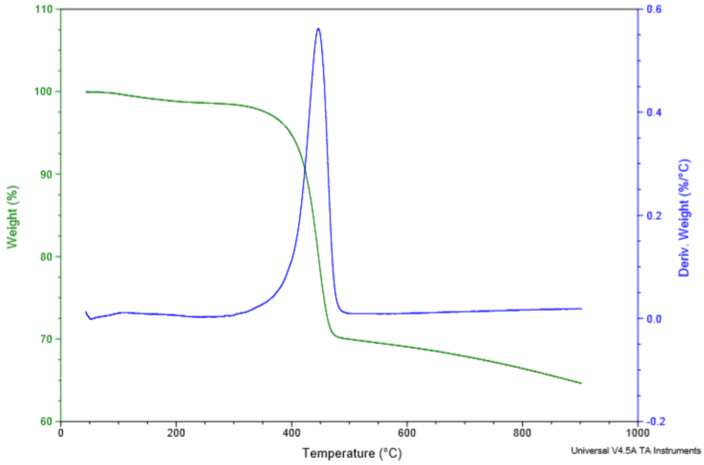
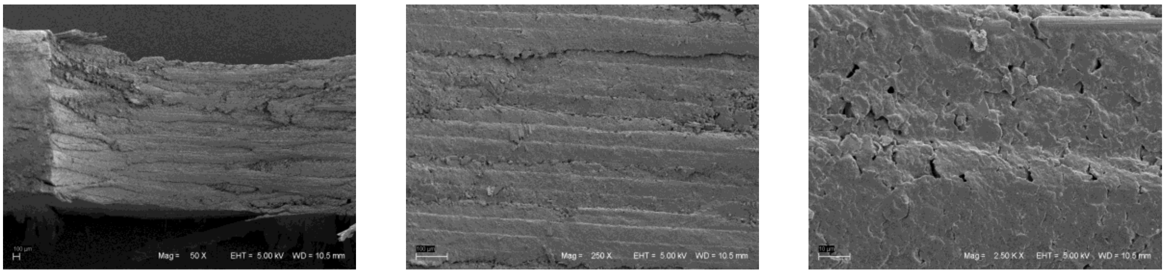


Figure 3 – TGA analysis of material.

The evaluation of matrix degradation can be seen in Fig. 4 where the interface between layers is observed. In these images there are no degradations of the matrix at the temperature that reached the process. Only the surface is observed, without deformations that could indicate a displacement of the fiber. This indicates that there was no removal of the fibers from the matrix, which maintained its integrity.

In the experiments carried out by Ben [25], up to the temperature range of 208 ° C, the same characteristic was observed. Only when reaching temperatures above 306 ° C did the matrix be removed and most of the fibers remained on the machined surface. The author identifies this change in failure mode due to the increase in temperature, the bond between matrix and fiber (interfacial) was easier to be broken. Another factor indicated by the author is the decrease in the friction coefficient between fiber and matrix.



(a) (b) (c)

Figure 4 - Drilling surface by SEM. a) View of the drilling surface (50x). b) View between layers (500x). c) amplification of the surface (2500x).

4. CONCLUSIONS

The following conclusions are observed from the temperature analysis in the drilling process of the CFRP:

- CFRP's thermogravimetric analysis (TGA) identified a degradation temperature above the temperature observed in the drilling process.
- SEM analysis of CFRP did not observe fiber deformations and matrix degradation. For the tool, no defects or wear were observed. Only the adhesion of particles of the polymeric matrix occurred.
- The drilling temperatures were lower than the degradation temperatures of the CFRP matrix.
- The drill has no defects or deformations at the cutting edges.

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