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Hole surface topography and tool wear in CFRP drilling

Gérard Poulachon[a]*, José Outeiro[a], Christophe Ramirez[a],Victorien André[a], Guillaume Abrivard[b]

[a]*Arts et Metiers ParisTech, rue porte de Paris, Cluny 71250, France*
[b]*Airbus Group Innovations, Technocampus Center EMC2, chemin du Chaffault, Bouguenais 44340, France*

* Corresponding author. Tel.: +33-385-595-342; fax: +33-385-595-370. *E-mail address:* gerard.poulachon@ensam.eu

Abstract

This paper deals with the hole surface quality when CFRP drilling. Mechanical instrumented operations have enabled to follow precisely the damage on the tool margins and the main cutting edges. The amount of uncut fibers according to the drill wear was evaluated with a roundness/cylindricity device versus the fiber's orientation and the tool damage. Thus, according to the hole's diameter tolerance, a wear criterion was defined to limit the number of holes achievable. This method has been carried out on unidirectional (UD) CFRP and then transposed on multidirectional (MD) CFRP. A model developed under Matlab was applied to predict the global topography of the hole surface.

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Keywords: Drilling, composite, surface integrity, tool wear.

1. Introduction

The increase in the manufacturing of new airplanes reaches 5% per year. Due to this new economic and environmental issues, the aeronautic sector is conducting research to improve their products through different technological solutions such as weight reduction, development of new manufacturing processes combined with innovative materials. All these solutions are more suitable for the environment. It is in this context that for several years, aeronautic companies are using huge amount of materials such as composites and titanium alloys. The combination of these two materials named stack, allows building light structures with maintaining good mechanical properties. Using those new methods, companies are able to make more efficient and more economical products. However, this practice has obviously led towards new difficulties in machining and especially in drilling operation.

The present study focuses on CFRP (Carbon Fiber Reinforced Plastic) drilling composite plate only, with the final objective to drill Ti/CFRP stacks. According to Bonnet et al. [1] during titanium alloy drilling, the cutting temperature may reach high value, whereas the epoxide resin of CFRP is subjected to resist approximately at 180°C, due to the carbonization. Moreover, tool wear will be accelerated due to the severe abrasive nature of the carbon fibers. As a consequence, the fiber delamination at hole surface will be discussed in this present study.

The main aim of this research is to find the consequences of the drill wear on the surface quality of the hole such us the uncut fibers and dimensional variation of the diameter in the case of an unidirectional (UD) CFRP composite. Then, the experimental approach used for UD will be extended to multi-directional (MD) CFRP composite.

2. State of the art

In order to study the influence of fiber orientation on the mechanical loading, it is necessary to use specific angles to describe the position of the tool cutting edge in relation to the carbon fiber orientation. Kivimaa [2] and McKenzie [3] have defined a notation for wood cutting that can be easily applied in the case of CFRP drilling by defining two orientation fiber angles regarding to the cutting edge and the cutting direction.

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Fig.1 describes those angles denoted by χ_1 and χ_2 which are respectively formed between the direction of the cutting edge or the cutting speed direction with the fiber axis.

For CFRP the cutting mechanisms depend on the orientation of the fibers [4] relative to the cutting direction (χ_2). Fig. 2 clearly shows the influence of the fiber orientation in particular for the value -45° which is not suitable for the surface quality and moreover will induce a rapid flank wear due to the elastic spring back of the fiber. The rake angle has also a significant influence on those mechanisms. Wang [5] summarized all of these possibilities as shown in Fig. 2.

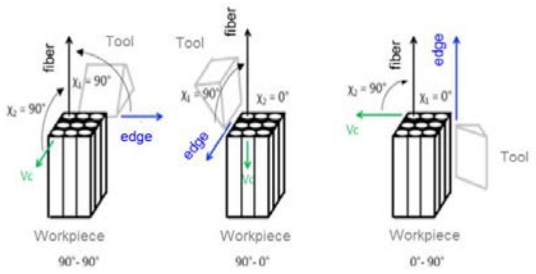

Fig. 1. Elementary configuration of cutting fibers (cutting modes) [3].

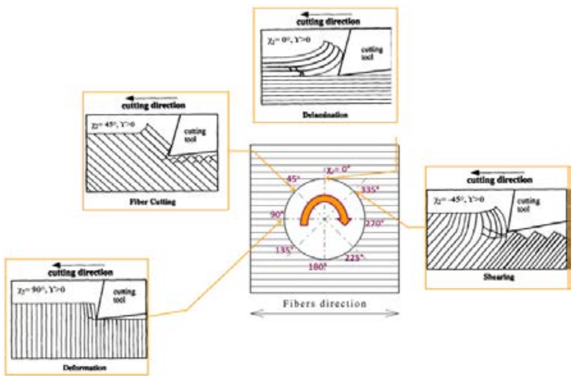

Fig. 2. Chip formation mechanisms in CFRP machining.

Many studies focus on peel-up or push-down delamination of the hole, but there are too few researches related to the surface integrity within the hole surface. The main defect which may appear is a high surface roughness due to uncut fibers cause to the cutting mechanisms mentioned by Wang [4]. For drilling unidirectional CFRP, χ_2 evolves from 0° to 360°, and according to Ramirez [6] the maximal surface roughness default takes place for χ_2 equal to 135° or 135°+kπ (315°).

Drilling is one of the most important operations in the manufacturing of aeronautic structures because of the large number of drilled holes. However, tool wear is an obstacle when drilling composite. Actually, due to its abrasive character, CFRP composite is causing fast tool wear leading to rapid surface damage.

Bonnet [1] has shown that 55% of the cutting torque is due to the main cutting edge and the remain portion (45%) is the contribution of the margins. Moreover, the cutting edges are responsible of 100% the feed force as highlighted in Fig.3.

Faraz [7] have introduced the measurement of the cutting edge roundness (CER) as a wear criterion in CFRP drilling.

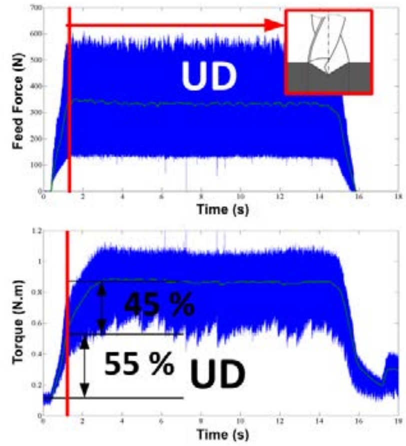

Fig. 3. Contribution of the tool cutting edges and margins on the drilling torque and feed force [1].

He showed in the case of uncoated carbide tools that the relationship between the CER and forces present a linear evolution. Rawat [8] highlighted that there is also chipping during CFRP drilling in combination with abrasive wear. He noticed that flaking occurs during the first holes and are partly due to carbon fibers. When the drill edges present a fine sharpness, this one is not enough resistant to undergo the high stresses imposed by the carbon fibers, leading to pulled out some carbide grains of the cobalt binder which induces chipping.

Park [9] has measured the wear on WC and PCD tools during CFRP/titanium stacks drilling. He noticed that the carbon fibers may weaken the cobalt binder and therefore accelerate the risk of drill chipping and fracture.

3. Experimental setup

The drilling tests were performed on a 5 axis Mikron HSM600 CNC milling center. After each drilled hole, tool geometry variation induced by wear was measured between 1.6 mm and 2.5 mm from the drill chisel edge in y-direction (*DL* distance in Fig. 4), using a Blum laser (4 µm resolution) installed in the machine-tool. Since the margins wear affects the hole diameter, the evolution of this one in function of the number of drilled holes was monitored.

Two uncoated carbide drills from SECO Tools, reference SD205A 12.0-56-12R1-T, having 140° tool tip angle, 12 mm of diameter, 1% back taper and a variable rake angle along the cutting edge (equal to 30° at the tool corner) were used. The hole dimensional tolerance used in this manufactured stacks is ø12G9 (+0.006/+0.049).

UD and MD CFRP composite plates of T800M21 with 60% of fiber contents and an epoxide resin have been drilled. The fiber diameter is approximately 5 µm and the ply thickness about 250 µm. MD CFRP composite plates presents an irregular arrangement (20%/-45°; 11%/0°; 18%/45°; 50%/90°). The thickness of all the plates was 35 mm.