CARBON FIBER REINFORCED PLASTICS MACHINING: SURFACING STRATEGY FOR REDUCING CUTTING FORCES.

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1. Introduction

Aeronautic composites are inhomogeneous and most often consist of two distinctly phases. The reinforcement fibers are relatively hard and brittle whereas the matrix is soft and ductile. The anisotropy causes some severe challenges when machining composites. people in the field often experience a trade off between two main problems; on one hand, keeping the composite parts integrity and quality, and on the other hand, reducing the wear of the cutting tools.
The high quality level required in aeronautic applications imposes a high quality cut of machined parts. Common defects that may occur during machining of these materials are delamination, over heat of the resin, uncut fibres, and pullout of the fibres. Delamination is when two or more layers are detached from each other, and may occur for example during drilling, when the drill exits the material. Overheating the resin may result in that the overall characteristics of the material is affected. Uncut fibres and fibre pullout may weaken the structure and cause unwanted wear on other structural parts. In order to partly avoid theses defects, our study is focused on the understanding of the cutting mechanism. As a first approach, the cutting forces are recorded during the cutting operation.
The understanding of the cutting mechanism have been introduced by Koplev followed by M.Ramulu, Wang & Arola [2] .They were first to report the cutting process in Carbon/epoxy composite during orthogonal cutting operation and classify the chip formation in five types depending on the carbon ply orientation. J.Y.S Ahmad [5] discussed about cutting forces in trimming operation. All theses authors conclude that the orientation of fibers is a relevant factor for explaining the cutting edge failure and the material defects.
Our study extends the cutting forces analysis to a high feed geometry tool. The most important part of the research is performed in CEROC (Researches and studies center on cutting tools technology), which is a jointly center between the company SAFETY, which provides cutting tool solutions, and the Laboratory of Mechanics and Rheology of the University of Tours (France).

2. Materials and experimental procedure:

The tests have been performed using a milling machine PCI METEOR 10 (horizontal spindle, Nmax=24000tr/min, P=40kW) equipped with a Kistler dynamometer (Type 9255B). The figure 1 shows the placement of the part during the test. A multi-axial carbon/epoxy composite (T800S/M21) was tested. The orientation of the plies is the following $[45/90/135/0]_s$ .The ply thickness was 0.26mm. For each test, the cutting conditions were kept constant, as described in table 1.

Cutting speed (m/min)	100
Fz (mm/tr/th)	0.3
Depht of cut (mm)	0.26
Radial engagement (mm)	35.6
Diameter (mm)	35.6
Lubrificant	dry

Table.1. Cutting conditions

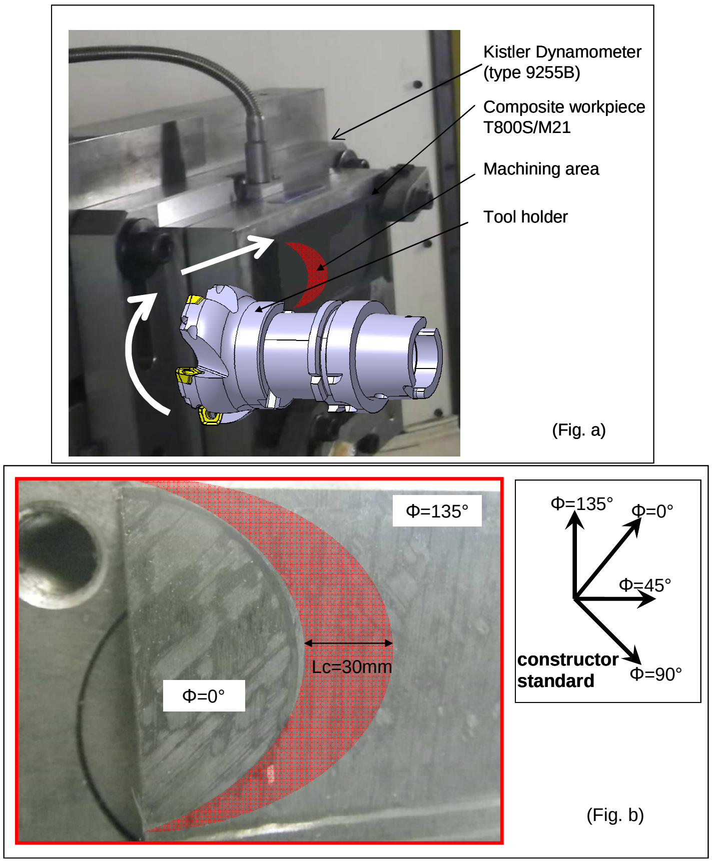

Fig.1.a & b. Fixture of the part and cutting strategy

2.1 Angle parameters

Fixed angles:

Regarding fibers orientation into the material, we are referring on the constructor prepeg layup sequence of the part this angle, Φ, is measured in the fixed frame of the part .Other fixed angles are defined in table 2, theses angles are taken into account for the resultant force calculation.

Lead angle (Kr)	19°
Radial cutting angle (ε)	-8°
Axial cutting angle (α)	10°

Table 2.

Variable angles θ et Ω:

θ is defined as the angle between the cutting speed vector and the fiber direction, this convention have been chosen to identify the cutting types related by Ramulu[2]. Figure 2 is extracted form his work, Type I,II,III,IV represented the cutting types, obviously during a milling operation, several types can appeared during the formation of one chip.

The engagement angle, Ω, is measured between the fixed frame and the rotating frame.

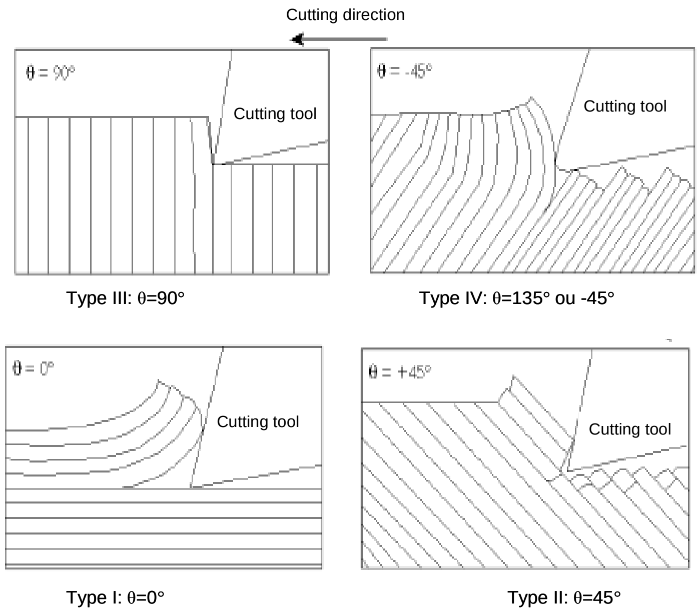

Fig.2. Cutting types introduced by Ramulu [2]

2.2 Milling parameters :

The cutting forces are important information for analyzing the cutting mechanism. In this work, the cutting forces were recorded by a Kistler dynamometer and calculated in a fixed frame Fxf, Fyf, Fzf. A rotating frame Fcx, Fcy, Fcz have been introduced with the angle, Ω, which is the angular position of the mill at every time. In Figure 3 and 4, frames Fcx, Fcy, Fcz and Fxf, Fyf, Fzf are represented. A final frame transformation F4cx, F4cy, F4cz takes into account the placement of the insert on the tool body. The parameters are the radial cutting angle, axial cutting angle and lead angle.
These frame transformations are applied to the mills in order to observe the forces intensity and direction on the cutting edge.

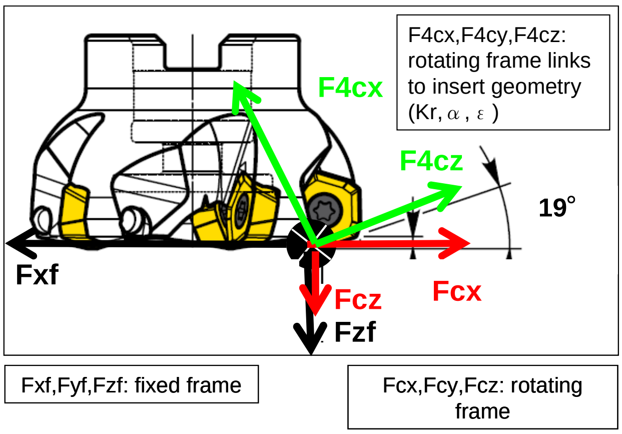

Fig.3. Side view of the mill, the 2 transformation frames are represented.

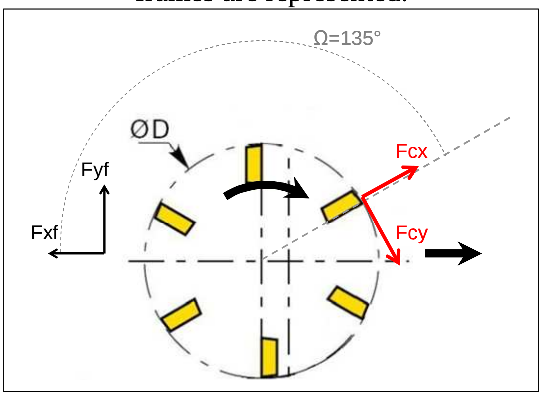

Fig.4. Upper side view of the mill, a rotation of 135° is applied as an example with Fcx, Fcy, Fcz as the rotating frame.

3. Results and discussions.

Figure 5 shows the acquisition diagram for the cutting force monitoring and the data post-treatment. The cutting forces signal is quite noisy, so we have to apply a low pass filter.

Figures 6, 7, 8, 9 illustrate the cutting forces evolution during chip formation in the plies at 135°,0°,45° and 90° respectively. For each test, a picture of the milled surface was taken, so that visual defects can be detected and recorded, for example fiber flaking or fiber pull out.

- The 135° machining ply: we have noticed a maximum resultant force F4c (green zone) obtained for type II and I which correspond to θ=45° et θ=0°. Flaking zone have been detected (red zone) for a minimal cutting resultant force.
- The 0° machining ply: we observed a peak level for the resultant force corresponding to type I and II, no flaking were detected in this configuration.
- The 45° machining ply: two cutting force peak values are observed, one for the entry of the edge inside the material corresponding to the type I and the second for the exit where θ=45°, type II. Flaking defects are localized in the first half of the chip formation. The value of the flaking is more important than the configuration 135° ply.
- The 90° machining ply: The cutting force peak values are obtained for θ=45°, at the beginning of the chip formation and the exit of the tool which correspond to a minimal chip thickness. Flaking defects are observed when θ=135° which is the maximal chip thickness.

Authors from [5-8] present work about cutting force recorded in trimming operation, their conclusions are the following:

- The tangential cutting force is maximal when θ evolutes between 90° and -45° (type III and IV).
- Defects under the surfaces can be detected for the type III and IV.

The high feed geometry (Kr=19°) which have been chosen in this study is justify by the fact that the cutting forces is minimal for the type III and IV. The different results obtained from the literature [5-8] can be explained by the high feed geometry which increases the axial cutting forces.

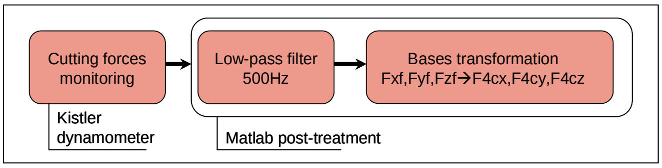

Fig.5. Signal acquisition and treatment diagram

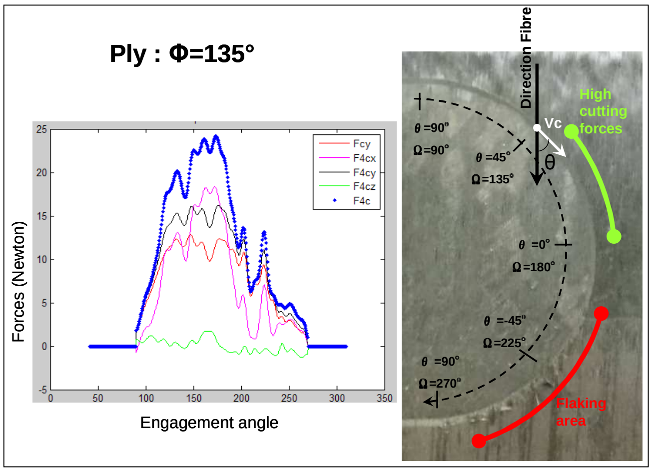

Fig.6. Cutting forces for 135° ply.

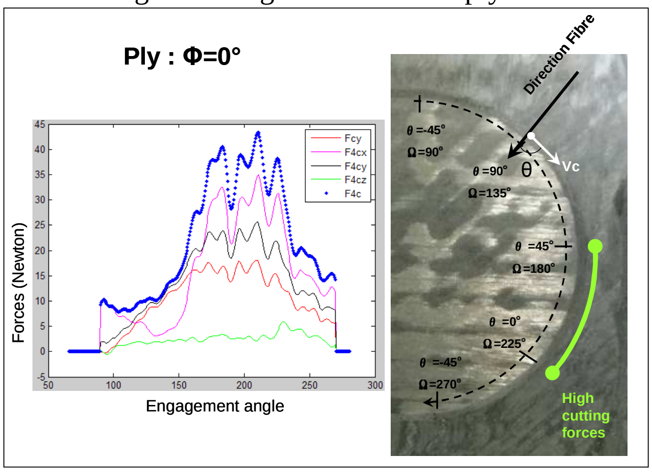

Fig.7. Cutting forces for 0° ply.

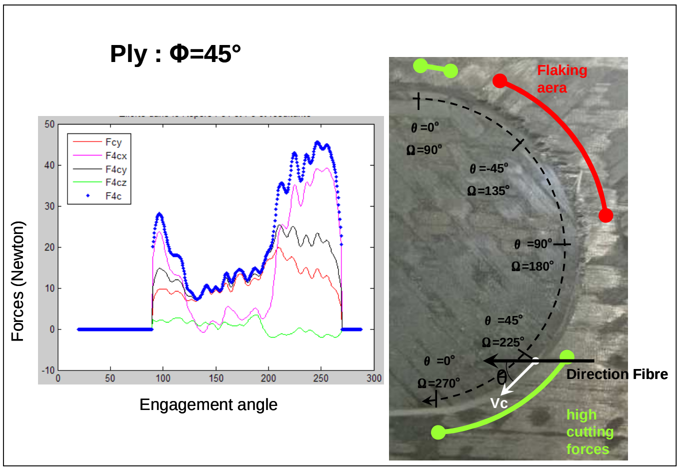

Fig.8. Cutting forces for 45° ply.

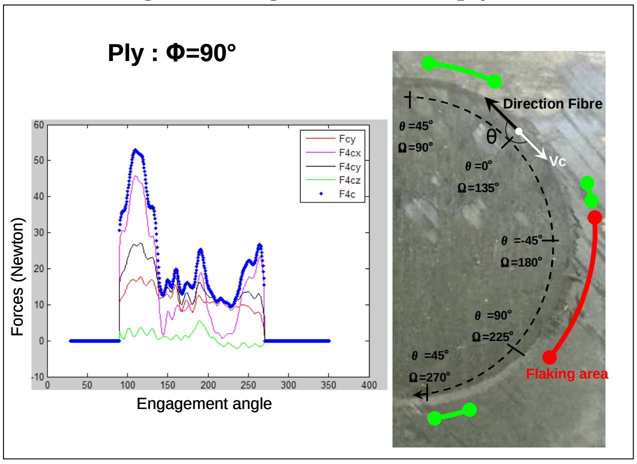

Fig.9. Cutting forces for 90° ply.

In order to observe the abrasiveness of each ply, we have performed high cutting speed machining (Vc=1000m/min), this strategy tends to accelerate the wear of the cutting edge. The depth of cut used was 1.04mm corresponding to 4 consecutive plies.

On the figure 10, the worn edge area are clearly identify and corresponding to the cutting type I and II, which confirms the previously results of section 3.

For comparison with [5-8], J.Y.S Ahmad concludes that for a cutting type between θ=0° à 75°, the axial component value is higher than the tangential components. He explains that the bouncing back of the fibers under the edge tends to generate high flank wear.

Maximal cutting forces have been obtained for type I and II and these types are represented in Fig.2. : Type I occurs when the fibers and cutting speed vector are in the same direction; fiber tends to bend like a beam under the action of the cutting tool. Type 2 is identified when the cutting speed and the fiber direction form a 45° angle; in this case fibers are broke by shearing load due to the action of the cutting tool.

Several authors [5-8] conclude that the axial cutting force is predominant between θ=0° à 75° (type I & II) compare to radial forces, Our work confirms these conclusions and extends the application to high feed face milling.

Two main conclusions appeared:

1. The high feed geometry decrease the cutting force for the cutting type III and IV. (Fig.2)

2. Abrasiveness of each ply depends on the cutting strategy. We recommend avoiding the cutting configuration Φ=135° and 0°, because in theses configurations the cutting edge is in contact with the type I and II. On the contrary, the configuration Φ=45° and 90° is advised to decreased the cutting forces.

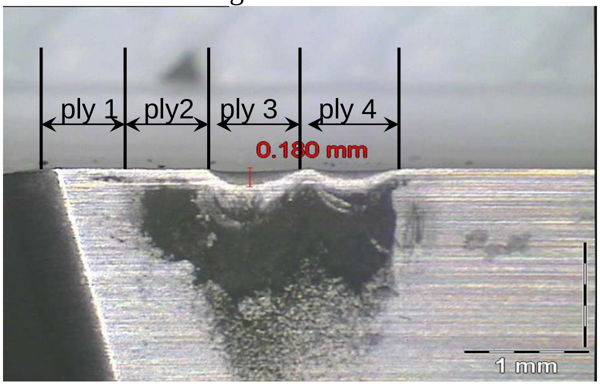

Fig.10. Flank wear on the insert PDKT0905DEFR11

4. Conclusions and future outlooks:

In this study, cutting forces have been monitored during a face milling operation of a multi-axial carbon/epoxy composite. The analysis of cutting forces helped us to determine the configuration which tends to increase the cutting forces.

Depending on the prepreg layup inside the composite material, a cutting strategy can be adopted. In our case the composite stack is $[45/90/135/0]_s$, where 45° is the upper ply and 0° is the bottom ply. Figure 11 shows an example of different cutting options for a radial engagement of 50% of the diameter and two plies thickness as the depth of cut.

Perspectives of this work are the following:

1. To quantify the real improving in tool life if such a strategy is adopted.
2. To quantify the diminution of the heat generated by the machining for avoiding thermal defects

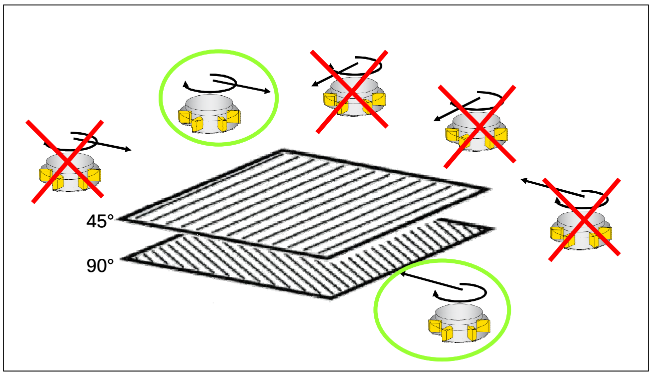

Fig.11. Cutting strategies for decreasing cutting forces.

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