Multi-layer Materials. Qualitative Approach of the Process

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ABSTRACT: The increasing part of multi-layer materials in the aerospace industry has created new machining problems. Indeed it is very difficult to machine these materials, particularly to drill them because they consist of materials with very different nature stacks, as strongly heterogeneous materials, such as carbon fibre composite, and materials monolithic, such as aluminium and titanium. The choice of cutting tool should be a compromise, to withstand high temperature involved during titanium drilling, as well as highly abrasive carbon fibre, while allowing the acquisition of drilling of aircraft grade.

This article, as a first step, presents a formalisation of multi-layer materials drilling isolating quality criteria, as well as the concept of stacking. Indicators have been defined in order to characterize these two basic concepts of multi-layer materials drilling, which are quality and stacking.

In a second part, a presentation of the structure of an experimental multi-layer model will be done by identification of its basic parts.

Key words: multi-layer materials, drilling, stacking, composite, aluminium, titanium, experimental model.

1 INTRODUCTION

The increasing use of composite materials in aerospace industry caused new industrial issues. Indeed these materials are frequently used in conjunction with other materials such as aluminium and/or titanium in order to form hybrid structures optimizing the ratios weight/strength to the constraints. Assembly of these materials by riveting or bolting requires realization of a very large number of holes. The different attributes of these materials, contribute to make the tools choice very difficult, cutting parameters and decrease tool life. This study provided an opportunity to present our work on multi-layer drilling such as: aluminium-composite-titanium.

As a first step, a drilling formalization of multi-layer materials is presented with introduction of two indicators:

- Quality indicator,
- Stacking indicator.

Second step will cover realization of an experimental multi-layer model based on the work of S. Laporte *[1]* and F. Dargnat *[2]*.

2 FORMALIZATION OF THE DRILLING OF THE MULTI LAYERS

2.1 *Quality Indicator*

The quality indicator makes it possible to position hole quality compared to tolerances of specifications. By through it, it's possible to see a

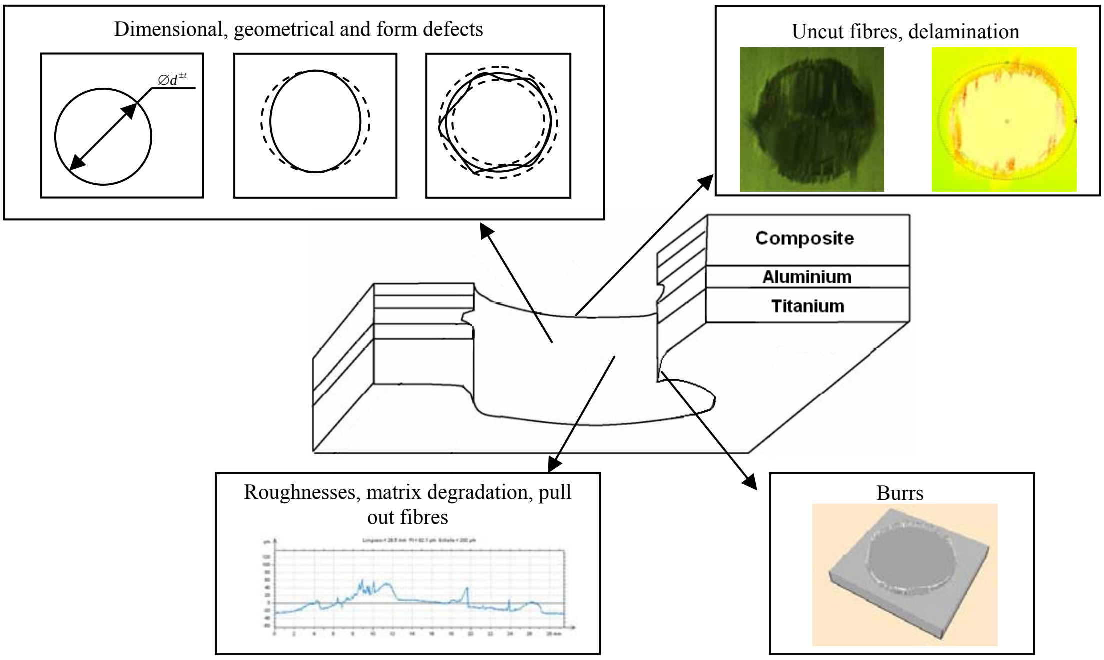


Fig. 1. Quality criteria of a multi-layer drilling

drift in hole quality and therefore anticipate a possible future exit of tolerance. This indicator takes into account various quality criteria of a multi-layer drilling.

Each quality criterion, presented in figure 1, is weighted according to its importance in overall quality of a drilling. Quality indicator is quantified *via* the following equation:

$$U = C_1 \times \left(1 - \frac{D_1}{d_1}\right)^{\alpha_1} + C_2 \times \left(1 - \frac{D_2}{d_2}\right)^{\alpha_2} + C_3 \times \left(1 - \frac{D_3}{d_3}\right)^{\alpha_3} + C_4 \times \left(1 - \frac{D_4}{d_4}\right)^{\alpha_4} + C_5 \times \left(1 - \frac{D_5}{d_5}\right)^{\alpha_5} \quad (1)$$

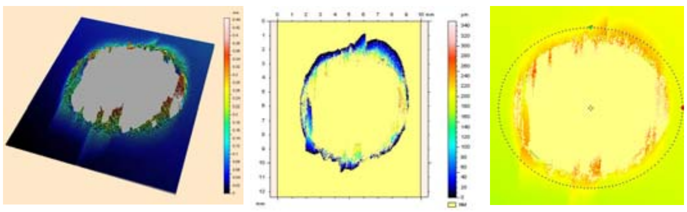
where C_i is the weighting factor of the i^{th} criterion satisfying:

$$\sum_{i=1}^{n} C_i = 1 \quad (2)$$

D_i is the value reached by this criterion, and d_i its tolerance.

Quality indicator is calculated if all values reached by the quality criteria are in tolerances. This is also valid for qualitative criteria such as uncut fibres.

As shown in figure 1, quantitative quality criteria of a multi-layer material ((carbon/epoxy composite)/aluminium/titanium) are geometrical and forms defects (ovalization, variation of diameter, cylindricity), roughness and finally the wide one of delamination in entry or exit for composite material and the height of burr for aluminium and titanium. Delaminated diameter is measured using a 3D roughness meter.



a) b) c)

Fig. 2. delamination diameters measurements

It enables to trace a circle including delaminated surface, as shown in figure 2. c. Criterion is expressed as a ratio, delaminate diameter on nominal diameter.

Let's analyze the i$^{\text{th}}$ term of equation (1):

$$\underbrace{C_i \times \left(1 - \frac{D_i}{d_i}\right)^{\alpha_i}}_{A_i} \quad (3)$$

A_i, term extracted from equation (1), must change in a same way than criterion in order that the weighting factor is efficient. Variation of the ratio $\frac{D_i}{d_i}$ depends on the criterion.

A normalisation factor (here α_i) is incorporated in each term to bring it into line.

The more the indicator tends towards 0, the more it approaches bounds of tolerances. The more it's close to 1, the better is the quality of the hole.

2.2 *Stacking Indicator*

This indicator quantifies the machinability of multi-layer materials. It makes it possible to evaluate potential difficulty of stacks machining (for example: carbon → aluminium → titanium or titanium → carbon → aluminium).
This indicator is defined in the following way:

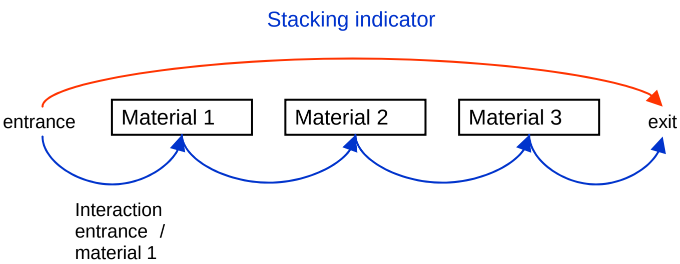


Fig. 3. Stacking indicator

Stacking indicator is the product interactions factors (figure 3).
Interaction factor quantifies impact on tool (wear) and the drilling quality during the transition from the first material to the next one.
For example during the transition from titanium to composite material (figure 4):

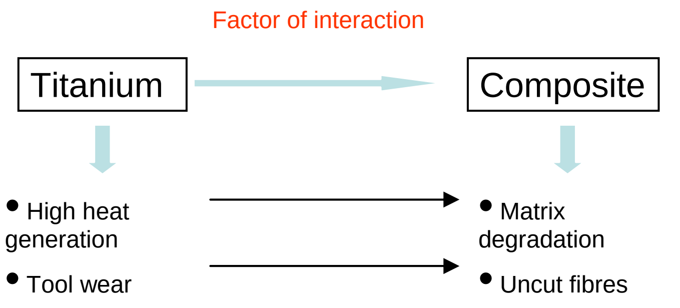


Fig. 4. Interaction factor in the case of the transition from titanium to composite

During tool passage through titanium, frictions between the tool edges and hole, and low thermal conductivity of titanium makes that practically all the heat generated during drilling is evacuated through the tool, resulting in high increase in tool temperature. Following this, epoxy matrix degradation occurred during tool passage through composite *[4, 5]*. Moreover high temperatures accelerated tool wear (loss of acuity) generates uncut fibres and increase in the geometrical defects and forms of the drilling.

The factor should therefore take into account the loss of tool life as well as consequences on quality of the hole.
In order to quantify this factor, tool wear experiments are necessary to quantify the relation between machined length and tool wear in a given material. But also by taking into account the bibliographical analyses on experiments in these materials in order to consider the drilling quality *[4, 5, 6, 7]*.

3 EXPERIMENTAL MULTI-LAYER MATERIALS MODEL

This model currently being developed consists of a geometric model and a behavioural model (based on the work done by S. Laporte [1]). Experimental multi-layer materials model is a comprehensive model constructed from several models involving tool geometry (geometrical model), cutting phenomena and the correlations between mechanical cutting actions and hole attribute (global behaviour model).

3.1 *Geometrical model*

The calculation of mechanical action requires knowing tool forms to determine specific cutting edges angles in each point. Geometrical model of drills enables to determine useful tools angles for the efforts prediction model, at each point on the cutting edge. It is based on work done by F. Dargnat *[2]*.
Geometrical model behaves as a "black box" which, when it incorporates input geometrical parameters and trajectories of grinding wheel, provides an output corresponding to drill geometry with specific cutting angles $(\gamma_0, \gamma_f, \kappa_r, \lambda_p)$ and their possible developments. The data of the drill are then introduced into the behavioural model.

3.2 *Global behavioural model*

The model is made up of several experimental models (as much as the layer number), built with S. Laporte approach, modelling the multi-layer global behaviour.
Experimental model takes into account the thermal aspect, tool wear as well as cutting forces during

drilling by means of six components cutting forces dynamometer developed by Y. Couétard *[3]*. Behavioural model goal is, by integrating input tool geometry as well as cutting parameters and nature of stacks (nature and sequences of materials, thicknesses) to obtain output tool wear and the drilling quality.

4 CONCLUSIONS

This study aims to formalize concept of multi-layer materials drilling, characterizing its quality, as well as the machinability of a stack. The quality criteria have been identified and a quantification method has been developed, particularly for specific criteria, such as delamination output or input of composite.

These criteria were then used to define an equation of quality, which tracks drift value, during series of drilling test.

Otherwise, stacking indicator will help quantify the machinability of a stack, and to allow an operator to adjust, a variety of tools and cutting conditions.

The multi-layer materials model architecture has been defined. It consists of two successive models, geometrical and behavioural models, and should be a predictive mathematic tool of the drilling quality.

The next step of this study will be to do series of test to define the interaction factor and experimental models. Experimental model will be realized for each material in order to build the global behavioural model.

Tests will also be conducted to validate experimental models.

REFERENCES

1. S. Laporte, Comportement et endommagement de l'outil en perçage à sec : application aux assemblages aéronautiques, Thèse de doctorat, Université Bordeaux I, spécialité Mécanique (2005).
2. F. Dargnat, Modélisation semi-analytique par approche énergétique du procédé de perçage de matériaux monolithiques, Thèse de doctorat, Université Bordeaux I, spécialité Mécanique (2006).
3. Y. Couetard, Caractérisation et étalonnage des dynamomètres à six composantes pour torseur associé à un système de forces, Thèse de doctorat, Université Bordeaux I, spécialité Mécanique (2000).
4. M. Ramulu, T. Branson and D. Kim, A study on the drilling of composite and titanium stacks, *Composite Structures* 54 (2001) 67-77.
5. D. Kim and M. Ramulu, Drilling process optimization for graphite/bismaleide-titanium alloy stacks, *Composte Structures,* 63 (2004) 101-114.
6. E. Brinksmeier and R. Janssen, Drilling of Multi-Layer Composite Materials consisting of Carbon Fiber Reinforced Plastics (CFRP), Titanium and Aluminum Alloys, *CIRP Annals - Manufacturing Technology*, Volume 51, Issue 1, 2002, Pages 87-90.
7. S. Gouleau, S. Garnier and B. Furet, Faisabilité du perçage d'empilages Multi Matériaux de type Aluminium/Composites, *Assises MUGV, Aix-en-Provence,* (2006).