

Chisel Edge Effect on Delamination when Drilling Thick Composite Materials with a Twist Drill

P. Rahme, Y. Landon, P. Lagarrigue, F. Lachaud and R. Piquet

Université de Toulouse

B. Marguet, J. Bourriquet and C. Le Roy

AIRBUS France

Copyright © 2008 SAE International

ABSTRACT

The drilling process is currently applied for bolt or rivet assembly of composite structures. As for metallic structures, the twist drill is the most commonly used cutter. At the hole exit, some delamination is generated with the use of a conventional twist drill. In this paper, an analytical model to calculate the critical thrust force in drilling composite materials is developed. This model relates the drilling critical thrust force to the delamination conditions (opening of cracks). It takes into account the chisel edge effect and the principal cutting edge effect of the twist drill. A close correlation between the experiment and the presented analytical model results is obtained. Finally, this study can be used to minimise drilling delamination at hole exit.

INTRODUCTION

Industrialists nowadays are increasingly interested in machining of composite materials. Such processes are often used for aeronautical assembly and repair. Drilling composite materials causes defects on entry, on the wall and on exit from the hole. Exit defects are considered to be major defects during drilling ([1], [2]). Rahmé et al [2] shows that cracks are initiated under the chisel edge and extended by the cutting edges. These defects are directly related to the axial penetration force that in turn depends on cutting conditions [3]. Thus, reducing delamination defects on exit involves addressing penetration force and thus cutting condition issues.

The axial drilling force depends on the cutter geometry, the material being drilled and cutting conditions [4]. A suitable choice of feed rate can reduce the delamination caused by the thrust force. A number of cutting models have been developed to model thrust force in relation to cutting conditions ([5], [6], [7], [8], [9]). The said models allow the axial drilling force to be expressed in relation to feed rate, the hole diameter and sometimes cutting speed.

The critical thrust force of delamination is the force corresponding to initiation of cracks and thus critical delamination. Moreover, several studies have been conducted to model the critical thrust force of delamination when drilling an orthotropic material. Rahme et al [1] and Piquet et al [3] modelled the axial thrust force for drilling of thin composite plates into a loading uniformly distributed on a thin circular orthotropic plate embedded round its edges and with a diameter equal to that of the tools. Hocheng et al ([4], [10], [11]) modelled the drilling critical thrust force assuming the material to be isotropic and proposing loading models in relation to the geometry of each tool. Fernandes et al ([6], [11]) estimated the maximum thrust force when one-shot drilling a composite material. In these studies, the loading models proposed take into consideration either the chisel edge effect or the principal cutting edge effect of the tool ([3], [4], [13], [14]).

The present article proposes a load model that takes into consideration both the chisel edge effect and the principal cutting edge effect simultaneously. This load model comprises a concentrated force applied to the centre of the plate and that represents the chisel edge effect and a load uniformly distributed over the entire plate representing the effect of the two principal cutting edges of a twist drill. Hocheng [4] showed that the chisel edge effect varies between 40 and 60% of the total thrust force applied. Now, the intensity of the resulting value of the distributed load was taken to be equal to the concentrated force in the present article. The principle of energy conservation was used as also that of the superposition method.

The values of the analytical model proposed were compared with the experimental results. This comparison shows that the results from this model are extremely close to experimental results, showing the significance of the chisel edge effect.



Documents
Document Sharing Hub

ANALYTICAL MODELLING

When drilling composite materials and when exiting the plate, the un-cut remaining thickness diminishes gradually. Resistance to bending and deformation of the last plies also diminishes. This can lead to decohesion of the matrix through to ripping of the last ply and breaking of the fibres. The exact shape of the delaminated surface is difficult to predict. In this model, a fictional defect close to being circular will be considered.

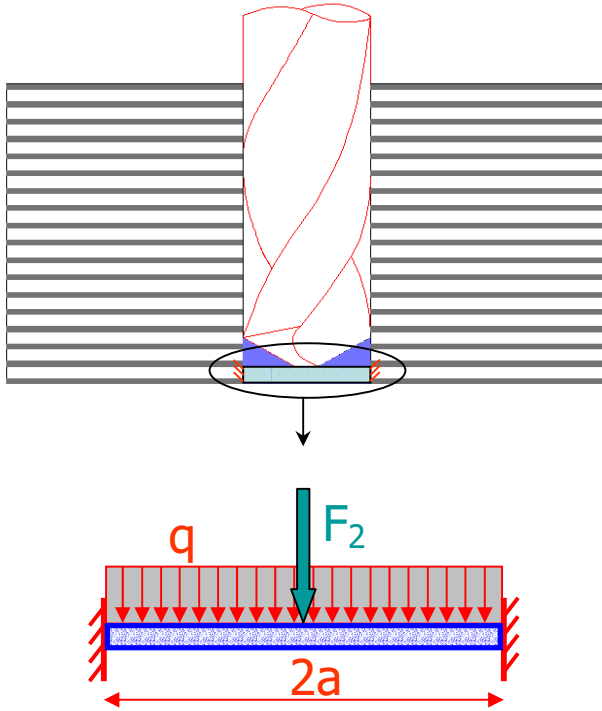


Figure 1: Modelling of twist drill/material contact

The part of the plate located under the drill was modelled as a thin circular orthotropic plate embedded around its edges as shown in Figure 1. This plate has the same diameter as the cutter. Contact of the cutter with the plate was modelled by a load uniformly distributed (q) over the entire circular surface and by a concentrated force F_2 applied to the centre of the plate. The first force represents the effect of the two principal cutting edges. The concentrated force represents the chisel edge effect concentrated on the centre of the plate. A thin plate with from 1 to 8 plies under the cutter was studied.

In the present article, the models for loading of a concentrated force and a distributed load were presented in polar form. This presentation simplifies resolution and gives the same expressions. However, a number of load models have been proposed but only the load model comprising a concentrated force and a distributed load was presented.

As a first approach, the crack initiation mode was considered perpendicular to the normal stress applied to the surface of the plies [15]. Only mode I was taken into consideration, with modes II and III being considered to be negligible. Moreover, global deflection was not taken into account and bending deformations were considered to be relatively insignificant.

Initiation of delamination was studied in terms of analysis of the critical energy in the case of the linear elastic fracture mechanics in mode I.

An energy-based approach based on the application of the theorem of virtual stress on the plate under the cutter will give the critical thrust force of delamination to be determined.

During drilling, movement of the cutter is associated with a distance dX . Stress produced by the thrust force F_z and function of this distance tends to propagate cracks and make the plate bend. The law of energy conservation is written according to Hocheng et al [4] :

$$\delta W = \delta U + \delta U_d \quad (1)$$

The cutter radius is the parameter that varies virtually. Now, δW the elementary virtual stress of the exterior forces is expressed :

$$\delta W = \frac{\partial W}{\partial a} \delta a = \frac{\partial \left(\iint_s F dS \right)}{\partial a} \delta a \quad (2)$$

δU is the virtual variation in potential energy U given by :

$$2U = \int_s \left[M_{xx} \frac{\partial^2 w}{\partial x^2} + M_{yy} \frac{\partial^2 w}{\partial y^2} + 2M_{xy} \frac{\partial^2 w}{\partial x \partial y} \right] ds \quad (3)$$

and δU_d is the variation in energy absorbed by propagation of the cracks. The energy of delamination U_d is the product of critical energy of propagation of the cracks in mode I (G_{IC}) and of the circular surface:

$$U_d = G_{IC} \times S = G_{IC} \pi a^2 \quad (4)$$

To calculate the potential energy and stress of external loads, transverse displacement $w(r)$ of the embedded circular plate with radius a has to be calculated in relation to the thrust force. Using Timoshenko's theory of plates [16] applied to the axisymmetrical circular plates loaded transversely with small deformations, and taking into account a shear force with intensity Q , the equilibrium equation for the plate is given on the polar coordinates by :