TOOL GEOMETRY EVALUATION FOR CARBON REINFORCED COMPOSITE LAMINATES

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SUMMARY
The use of composite laminates in complex structures has increased significantly. However, there are still some issues when considering their use, mainly related with machining, leading to some difficulties and lack of acceptance. In this work, a methodology to evaluate drill geometry and feed rate based on thrust force and delamination extension is presented.

INTRODUCTION

For the past decades composite materials are increasing their importance as one of the most interesting groups of materials, due to their unique properties of low weight, high strength and stiffness.
One of the main machining operations needed in composite structures is drilling, as it is required when bolts, rivets or screw are used to join different parts. Usually, it is accepted that drilling can be carried out using conventional machinery with suitable adaptations. However, as composites are non-homogeneous, drilling causes some difficulties. In fact, some damage in the region around the hole boundary is evident after a drilling operation is accomplished, being delamination the most serious one as it can reduce the load carrying capacity of the joint. The main mechanism responsible for delamination is the indentation effect caused by the quasi-stationary drill chisel edge (Hocheng et al. 2005). This effect can be diminished by a correct choice of tool geometry and/or cutting parameters (Hocheng et al 2006). In general, it is accepted that a drilling process that reduces the thrust force exerted by the drill chisel edge can prevent delamination occurrence (Dharan et al 2000, Davim et al 2003, Durão et al. 2008). Another possibility for delamination reduction is an adequate design of the cutting tool – drill – which, combined with proper machining parameters, can help in delamination prevention (Persson et al 1997, Piquet et al 2000, Hocheng et al 2006, Tsao et al 2007).

In this work, a comparison on the thrust force during drilling and delamination extension after drilling has been accomplished considering five different drill geometries – twist with two point angles, Brad type, Dagger type and bidiametral, figure 1. The involved thrust force was monitored during hole machining and the delamination extension was computational analyzed by enhanced radiography and techniques of image processing and analysis. An experimental procedure was planned and results evaluated.

MATERIALS AND METHODS

In order to perform the experimental work planned, plates using prepreg CC160 ET 443 with a cross-ply stacking sequence and 24 layers were produced. The plates were then cured under 300 kPa pressure and 130 ºC for one hour, followed by cooling. At the end, plate thickness was 4 mm. Then, the plates were cut in coupons of 165x96 mm^2 for drilling experiments.

The experimental work was divided in drilling of the laminate plates for thrust force monitoring with a *Kistler 9257B* dynamometer associated to an amplifier and a personal computer for data acquisition and processing. Drilling operation was carried out in a 3.7 kW *DENFORD Triac Centre* CNC machine. The second step was delamination evaluation by enhanced radiography and techniques of image processing and analysis. With this goal, plates were immersed in di-iodomethane for contrast for one and a half hour and radiographed. Acquired radiographies were scanned for delamination around the hole measurement. Details of this process can be found in Durão et al (2008).

a) b) c) d)

Figure 1 Drills: a) twist (120º / 85º); b) Brad; c) Dagger; d) bidiametral

A total of five tungsten carbide drills with 6 mm diameter and different geometries were used: a twist drill with a point angle of 120º, a twist drill with a point angle of 85º, a Brad drill, a Dagger drill and a customized step drill, Figure 1. Cutting parameters, defined based on previous works, were the following: cutting speed of 53 m/min, corresponding to a spindle speed of 2800 rpm; and three feed rates, respectively 0.02, 004 and 0.06 mm/rev.

RESULTS AND DISCUSSION

Results considered for thrust force are the maximum values observed during drilling. The force values were always averaged over one spindle revolution, due to signal variation along drill rotation and are the average of six experiments performed under identical conditions.

Variation of thrust force with feed rate and drill geometry can be observed in Figure 2. From that figure, is clear that larger feed rates cause an increase in the value of the maximum thrust force during drilling, whatever drill is used. For this reason, the likelihood of delamination damage, closely linked to the existence of a trigger value for delamination onset (Hocheng /Dharan 1990), becomes greater with larger feeds.

Regarding tool geometry, Brad drill has always the highest values of thrust force while the lower ones were obtained with Dagger drills. When comparing the two twist drills, a

120º point angle allows for larger thrust force reduction than an 85º point angle drill. The bidiametral drill has not confirmed the predicted reduction of thrust force.
Regarding delamination, considering Delamination factor – Fd – (Chen, 1997) and results of delaminated diameter accomplished by enhanced radiographies and techniques of image processing and analysis, a comparison graphic is presented in figure 3. From the results of damaged region is possible to identify a relationship between feed rate and delamination. So, an increase in feed will cause extended delamination. This result confirms that the selection of an appropriate feed rate can help on delamination prevention.

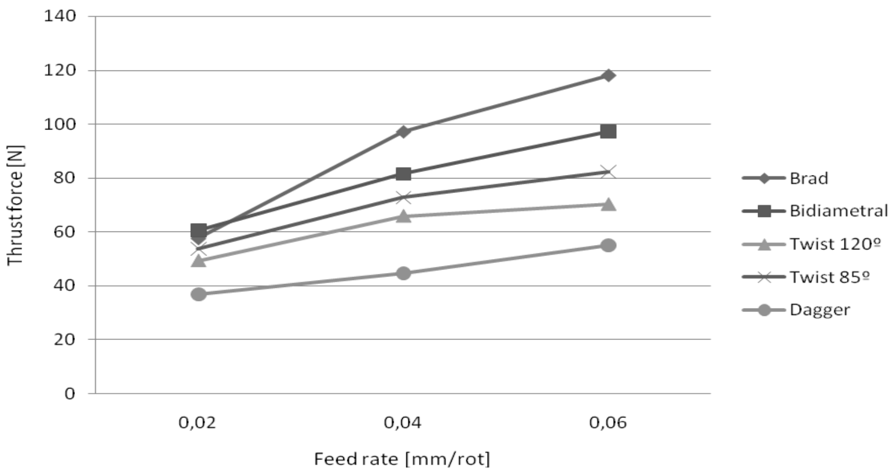

Fig. 2. Evolution of thrust force with feed rate for the drills used in this work.

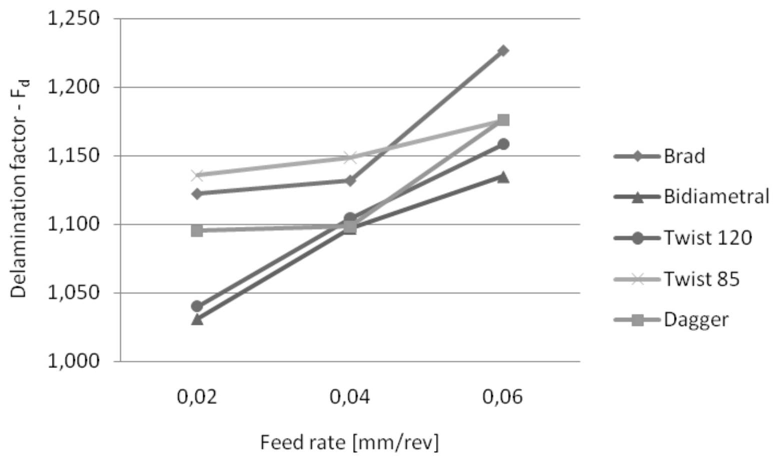

Fig. 3. Evolution of delamination factor – F_d – with feed rate for the drills used.

For the feed rates selected, the behavior of the five drill geometries becomes different with each feed rate. For the medium one, the values of delamination are very similar, while for the smaller and larger feeds, there is an advantage on the use of bidiametral or 120º point angle twist drill. Corresponding to higher thrust forces during drilling, Brad drills had the higher damaged zone. The lower thrust force values of Dagger drill did not correspond to less delamination, evidencing the importance of tool tip geometry on delamination onset and propagation.

CONCLUSIONS

Carbon/epoxy laminates were drilled with the objective of comparing five different tool geometries. Results used for drill geometry comparison were the maximum axial thrust force during drilling and delamination around the hole. Experimental work has involved three feed rates combined with a pre-selected cutting speed. Results show that an adequate combination of drill geometry and parameters can help to reduce delamination.

Low feed rates seem appropriate for laminate drilling, reducing the axial thrust force and, therefore, the risk of delamination onset and propagation.

Additionally, an adequate tool selection can help on damage minimization. For the experimental conditions considered the most adequate commercial tool is the 120º point angle twist drill. Bidiametral drill represents an adequate option for a tool as well.

Tool geometry had influenced the results both for force and delamination. It is interesting to remark the diverse effect of feed rate on delamination according to the tool used, as the slope of the delamination values lines for each tool is dissimilar.

Based on the work accomplished, and considering the parameters used, a 120º twist drill should be used for minimal delamination while the bidiametral drill still needs further improvements.

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