Cryogenic Machining of Carbon Fibre

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Abstract

Processing of composite structures commonly consists of drilling of holes for joining and assembly of different components. Drilling of composites presents a number of challenges, namely, delamination, excessive burr formation, fibre splitting, heat affected zones and significantly reduced cutter tool life. This paper explores the application of cryogenic CNC machining methods for machining of holes in carbon fibre, typically used in aerospace. Test parts are drilled using a range of different machining parameters, standard carbide tooling and different machining conditions, namely, dry, and cryogenic using liquid nitrogen. The results show that cryogenic methods significantly reduce the amount of delamination and surface roughness, particularly at elevated machining parameters. Cryogenic CNC machining also provides a realistic method for drilling of carbon fibre composites that reduces delamination and surface roughness.

1. Introduction

The use of composites in engineering is increasing, particularly for applications that require high strengths to weight ratios, such as in the aerospace and motorsport industries. Composite structures consist of lay up techniques and depend on the required final geometry and the end application. Each layer is built up in different directions to provide maximum stiffness and strength and then cured using a combination of heat and pressure. Adding holes in the layup process is time consuming and difficult and in some cases result in distortion of features and splitting of fibres. In this paper current composite machining methods are outlined and discussed. The concept of cryogenic CNC machining is proposed and demonstrated using carbon fibre as an example. A set of experimental results is provided detailing captured SEM images from the different machining approaches.

2. Machining of composites

Machining composites is typically related to two areas, namely drilling and edge de-burring. Drilling of holes is of particular importance as it is the primary method in which different parts are assembled, for example wings on aircraft. Davim *et al.* [1] investigated drilling CFRP (carbon fibre reinforced plastics) using carbide tools to establish correlations between cutting speed and feed based on the power consumed, the specific cutting pressure and the delamination factor. Feed was the most influential factor for delamination at the entry point and speed was the most influential at the exit point. Wen *et al.* [2] investigated drilling of CFRP in regard to cutting forces, tool geometry and drilling parameters. As opposed to other studies the key finding was related to increases in temperature. Specific cutting conditions were proposed to avoid heat damage and burning during drilling on both entry and exit faces. Rahman *et al.* [3] machined CFRP by varying speed, feed and depth of cut and by using 3 different tool inserts. For short fibres tool wear, surface finish and cutting forces fluctuated with respect to machining parameters. However for long fibre composites tool wear reduced when machining at reduced speeds. Using cubic boron nitride inserts showed better tool wear characteristics and reduced surface roughness when compared to carbide and conventional ceramic inserts.

Current methods have focused primarily on conventional drilling. Initial attempts at cryogenic machining of Kevlar composites [4] illustrated the viability and improved machinability when compared to conventional machining. The cryogenic method also provides a method to reduce cutting zone temperature significantly. The following sections provide details of the experiments conducted.

3. Experiments

Based on the literature pertaining to machining of composites, it can be seen that there is a need to investigate drilling of composites in order to reduce heat during machining, reduce surface roughness and delamination. The setup consists of using the University of Bath cryogenic machining facility [5] as detailed in figure 1. Two different tests namely dry machining and cryogenic machining using liquid nitrogen were conducted on samples of carbon fibre using 8mm diameter 2-flute drills.

Machining parameters in the range of between 5000 – 8000rpm and 500 – 1000 mm/min were used for both sets of tests and 32 holes were drilled.

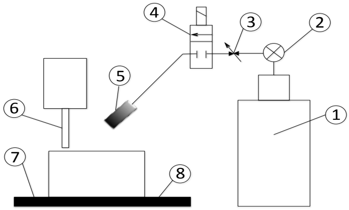

Figure 1: Schematic setup for cryogenic machining, 1-Liquid nitrogen Dewar, 2-pressure gauge, 3- gate valve, 4- solenoid on/off valve, 5- specially designed nozzle, 6- cutting tool, 7- workpiece, 8- machine table

4. Results

It was observed that the machining condition alongside machining parameters plays a critical role in increasing the quality of the machined hole. From the analysis a number of influencing machining mechanisms were observed, namely, delamination and surface roughness. Delamination reduced as a result of cryogenic machining and is primarily attributed to brittle fracturing of the start and exit faces of the carbon fibre as opposed to temperature induced ductile deforming of the fibres. In conventional drilling there is a tendency for the material matrix to deform, causing delamination and distortions in the entry and exit faces. In addition, it was observed that increases in speed and feed reduced the onset of delamination. Surface roughness for dry machining increased at high feed rates (1000mm/min). For the cryogenic machining method the surface roughness reduced as the feed rate increased and also remained more constant. Figure 5 shows an example of the surface roughness comparison. Figures 2 and 3 provide SEM images detailing the machined surfaces. It can be clearly observed that the cryogenic machining method produced less delamination and the surface quality is better, with considerably less micro cracking, when using the same machining parameters. (1000mm/min,8000rpm). The optical flash thermography indicates that using cryogenic methods, leads to a reduction in delamination particularly at the entry face as illustrated in figure 4.

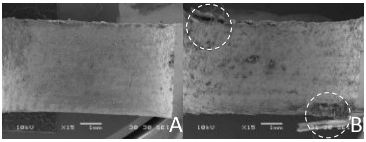

Figure 2: (A) Cryogenically machined & (B) dry machined sample

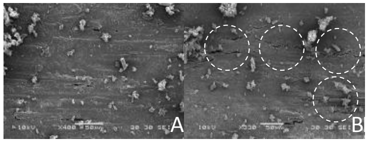

Figure 3: (A) Cryogenically machined & (B) dry machined sample

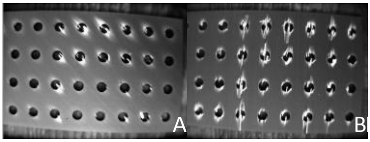

Figure 4: Optical flash thermography - Entry face (A) Cryogenic, (B) Dry.

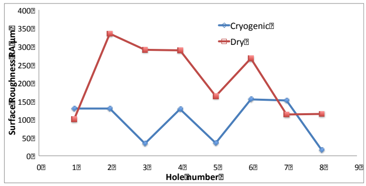

Figure 5: Surface roughness comparison.

5. Conclusions

A novel processing method has been developed for improved drilling of carbon fibre composites using cryogenic CNC machining. From the experimental study it has been observed that delamination at both entry and exit faces is reduced, surface roughness is more consistent and reduces with increases in speed and feed, therefore also reducing the drilling time. The exit faces exhibit reduced delamination as a consequence of the cryogenic method and also as a result of higher cutting speed (8000rpm) and feed rate (1000mm/min). In order to continue to validate this process, further experiments are required, particularly to analyse tool wear and machining of other composites. However, what is clear from this study is that using cryogenic methods provides a solution that can reduce delamination, reduce surface roughness and micro cracking of carbon fibre composites.

References:

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