Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 67 (2018) 404 – 409

www.elsevier.com/locate/procedia

11th CIRP Conference on Intelligent Computation in Manufacturing Engineering - CIRP ICME '17

Multiple sensor monitoring for tool wear forecast in drilling of CFRP/CFRP stacks with traditional and innovative drill bits

Alessandra Caggiano[a,b], Francesco Napolitano[a,c,*], Luigi Nele[c], Roberto Teti[a,c]

[a]Fraunhofer Joint Laboratory of Excellence on Advanced Production Technology (Fh-J_LEAPT UniNaples), Naples, Italy
[b]Dept. of Industrial Engineering, University of Naples Federico II, P.le Tecchio 80, 80125 Naples, Italy
[c]Dept. of Chemical, Materials and Industrial Production Engineering, University of Naples Federico II, P.le Tecchio 80, 80125 Naples, Italy

* Corresponding author. Tel.: +39-081-7682371; fax: +39-081-7682362. *E-mail address:* francesco.napolitano4@unina.it

Abstract

A multiple sensor monitoring procedure is developed with the aim to perform tool wear forecast in drilling of CFRP/CFRP stacks. Experimental drilling tests with a traditional twist drill bit and an innovative step drill bit are carried out using a multi-sensor system to acquire thrust force and torque signals during the process. The tool wear curve for each drill bit under different drilling conditions is obtained by measuring the tool flank wear. An artificial neural network for pattern recognition is developed to find correlations between selected sensor signal features and tool wear state, with the aim to forecast the tool wear values during drilling based on the information extracted from the acquired sensor signals.

Keywords: Drilling; Composite material; CFRP; Tool wear; Sensor monitoring; Artificial neural network.

1. Introduction

The use of new structural materials such as carbon fiber reinforced plastics (CFRP) allows for a substantial weight reduction on aircrafts, which positively affects emissions and management costs through a lower fuel consumption consistent with nowadays environmental requirements [1].

Due to the difficulties in realizing welding operations or adhesive joints for the assembly of CFRP components, mechanical joining techniques such as riveting are generally employed to realize strong and reliable joints. This is the reason why drilling is the most widespread CFRP machining process in the aeronautical industry. However, the anisotropic nature of the material, the very rapid tool wear caused by the abrasive carbon fibers and the high concentrated efforts and vibrations that may cause damages affecting material integrity, processed surface quality and aspect, make the machining of CFRP parts a great challenge for manufacturing engineers [2-7].

With the aim to reduce the tool wear in order to improve the quality of the final product and cut off the costs related to frequent tool changes, some recent studies have been focused on the development of new drill bit geometries [8-12]. Efforts have been also spent for modelling the thrust force during drilling operations, which has been found to directly affect the quality of drilled holes [13-17]. To achieve a high productivity, while preserving the integrity of the workpiece during drilling of CFRP components, in-process tool wear state monitoring is crucial. This can be performed by an on-line real-time multiple sensor monitoring procedure [18].

In this study, experimental CFRP/CFRP stack drilling tests are performed with a traditional twist drill bit, commonly used in the aircraft industry, and an innovative geometry drill bit. The drilling process is monitored through a multiple sensor system able to acquire thrust force and torque signals during the process. Every ten drilled holes, the tool flank wear is measured using an optical device to obtain the tool wear development curve for each drill bit. An artificial neural network (ANN) for pattern recognition is developed to find correlations between selected sensor signal features extracted in the time domain and tool wear state, in order to realize cognitive tool wear forecast during the CFRP drilling process [19-21]. The ANN forecast for both drill bits is evaluated in terms of MSE prediction error.

doi:10.1016/j.procir.2017.12.233

2. Experimental setup

2.1. Workpiece details

The workpiece employed for the experimental drilling tests is represented by CFRP/CFRP stacks. The target is to reproduce the real aeronautical industry operating conditions, in which these types of laminates are superimposed and then drilled together to allow the subsequent riveting.

The CFRP/CFRP stacks under study are composed by two overlaid symmetrical and balanced laminates. Each laminate has a thickness of 5 mm and is made up of 26 prepreg unidirectional plies arranged according to the following stacking sequence $[\pm45_2/0/90_4/0/90/0_2]_s$. A very thin fiberglass/epoxy ply, reinforced with 0°/90° fabric (areal weight 80 g/m2) is laid on the top and bottom of each laminate. The prepreg plies are made of Toray T300 carbon fibres and CYCOM 977-2 epoxy matrix.

The laminates were fabricated by hand layup, vacuum bag moulding and autoclave curing. The surface texture of the laminates on the bag side is very irregular compared to the mould side. Therefore, the two CFRP laminates of each stack were placed with the bag side in contact to realize the drilling process under the severest possible conditions.

2.2. Tools details

With the aim to develop a tool with an innovative geometry in order to increase tool life and productivity by reducing the tool wear rate, a step drill with innovative geometry was employed. The latter is a 2-flute 6.35 mm diameter with 120° point angle and 20° helix angle made of tungsten carbide (WC) (Fig. 1).

In order to have benchmark data in terms of sensor signal features and tool wear, a traditional tool, i.e. a 2-flute 6.35 mm diameter with 125° point angle and 30° helix angle tungsten carbide twist drill (Fig. 2), was also employed.

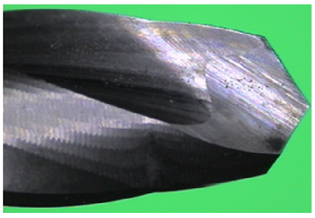

Fig. 1. Innovative step drill bit.

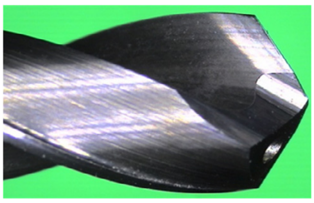

Fig. 2. Traditional twist drill bit.

Table 1. Experimental testing conditions.

Feed (mm/rev)	Spindle Speed (rpm) 2700	6000	7500
0.11	X		
0.15		X	
0.20		X	X

2.3. Cutting parameters

Different cutting parameters were adopted for the experimental drilling tests to study the drill bit behavior under diverse cutting conditions. Three feed values (0.11 mm/rev, 0.15 mm/rev and 0.20 mm/rev) and three spindle speeds (2700 rpm, 6000 rpm and 7500 rpm) were employed as shown in Table 1. For each experimental condition, 60 holes were realized with the same drill bit. A CNC drilling centre was used for the experimental drilling tests on the CFRP/CFRP stacks.

3. Sensor signal processing and features extraction

3.1. Multiple sensor monitoring system

The multiple sensor monitoring system employed during the experimental drilling tests is composed of:

- Force sensor (Kistler-9257A piezoelectric dynamometer) which allows to acquire the thrust force along the z-direction, F_z.
- Torque sensor (Kistler-9277A25 piezoelectric dynamometer) which allows to acquire the cutting torque along the z axis, T.

The analogue signals acquired by the above sensors were digitized at 10 kHz sampling rate by a National Instruments NI USB-6361 DAQ board. This sampling rate was chosen based on the Nyquist-Shannon sampling theorem.

3.2. Signal segmentation, features extraction and selection

The sensor signals acquired by the multiple sensor monitoring system during the experimental drilling tests included head and tail transient portions which do not belong to the actual machining process. As these signal portions are not relevant for process monitoring, they had to be removed in order to consider only the signal segment corresponding to actual machining [19-21].

The signal segmentation procedure was performed on the basis of the F_z signal and synchronically extended to the T signal. The automated segmentation procedure to cut out transient signal portions is based on the identification of the machining start point and the machining end point.

The isolation of the relevant signal segment allows to perform the extraction of functional sensor signal features that may be correlated with tool state [5]. A statistical approach in the time domain was applied for feature extraction. Several statistical signal features can be extracted from a time domain