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Temperature measurements for the tool wear and hole quality assessment during drilling of CFRP/CFRP stacks

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Abstract

Carbon Fiber Reinforced Polymer (CFRP) laminates are widely employed in the aerospace industry as they are lightweight materials with high mechanical strength. Drilling, that is the most common machining process for CFRP parts, may induce several types of defects in the laminates. This paper is aimed at the correlation of parameters representative of the hole quality and tool wear with data from thermographic analysis with the aim to investigate the possibility to assess the hole quality in real time, and to detect the need for tool replacement without physical measurements on the tool. The developed procedure is applied to the holes produced by two different geometry tools.

Keywords: Drilling; CFRP; Delamination; Image analysis; Tool geometry; Termography; Hole quality; Sensor monitoring; Industry 4.0

1. Introduction

Carbon Fiber Reinforced Polymer (CFRP) laminates are widely employed in the aerospace industry as they are lightweight materials with high mechanical strength. Since these laminates are neither homogeneous nor isotropic, their machining is particularly difficult [1-2]. Drilling, which is the most frequent process applied to CFRP laminates, raises problems that can be related to subsequent damage in the region around the holes [3-5]. Different types of defects, significantly impairing the product performance, may be generated when drilling [3-4].

One of the most common parameters used for the evaluation of drilled hole quality is the delamination; it may affect the structural integrity of the laminate and cause potential long-term performance deterioration. Delamination occur both at the entry (peel-up delamination) and exit (push-out delamination) of the hole [3-5].

The aim of this paper is to perform on-line assessment of hole quality and tool wear during drilling of CFRP/CFRP stacks through in-process thermographic measurements using an infrared temperature sensor.

The opportunity to find a suitable correlation between the acquired temperature data and the stringent hole quality parameters established by the aerospace industry is very appealing in a zero-defect manufacturing perspective.

This would enable a higher automation of the drilling process, allowing for higher productivity and reduced scrap rate by enabling an optimized tool replacement strategy based on real-time temperature monitoring and hole quality evaluation.

This automation can support the development of a ‘smart’ factory of the future in the Industry 4.0 framework, where autonomous decision-making systems are supported by advanced sensor monitoring of physical processes.

2. Experimental setup

2.1. Workpiece details and experimental procedure

Experimental drilling tests were carried out on stacks made of two CFRP laminates both composed of 26 CFRP prepreg plies made of CYCOM 977-2 epoxy matrix and Toray T300 carbon fibres with stacking sequence $[\pm45_2/0/90_4/0/90/0_2]_s$. The

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total thickness of each CFRP laminate was 5 mm, and a very thin fiberglass/epoxy ply reinforced with 0°/90° fabric was placed on the front and back surfaces of the laminates.

Laminates were fabricated by hand lay-up, vacuum bag moulding and autoclave curing. The surface texture of the laminates on the bag side was very irregular compared to the mould side which is smooth (Fig. 1).

To accurately reproduce the drilling conditions in the aerospace industry, the two laminates were stacked and drilled together. The stacked CFRP laminates were placed with the bag side in contact to test the severest possible drilling conditions.

Image analysis was conducted on 60 consecutive holes with the same cutting conditions using two different tools:

- Traditional tool: a two-flute twist drill made of tungsten carbide (WC), Ø6.35 mm, which features a 125° point angle (Fig. 2 (a) and (b)).
- Innovative tool: a two-flute step drill made of tungsten carbide (WC), with the diameter growing from 4.9 mm to 6.35 mm in two steps with sharp elliptical margins (Fig. 2 (c) and (d)).

Temperature data acquisition during the experimental drilling tests was performed using an Infrared Optris PI 450 camera with 80 Hz framerate and an optical resolution of 382 x 288 pixels providing real-time thermographic monitoring.

The Optris PI Connect software allows capturing videos, instantaneous pictures and temperature profiles from which the required data are extracted along a selected direction or within an area of desired geometry inside the field of view (Fig. 3).

The characteristic emission value for this type of CFRP material, commonly used in the literature, is 0.85 (measured according to the procedure of ASTM E 1933 standard [10]), therefore this coefficient was set in the software.

To proceed with the temperature measurement during the experimental drilling tests, the camera was placed inside a metal cylinder under the laminates fixture. This cylinder was protected with a film to prevent the powder, generated during the drilling process, from infiltrating and causing an alteration in the investigation of the temperature (Fig. 4)[11].

From the processing of the data acquired through the thermographic camera software it was possible to obtain a temperature/time diagram for each hole drilled. To speed up data acquisition, temperature measurements were carried out only for odd number holes. This is sufficient to observe the temperature trends since the temperature difference between a hole and the next one is just a few degrees.

2.1. Drilled hole quality parameters

The holes drilled on the CFRP/CFRP stacks have stringent quality requirements related to their geometry, dimensions and surface integrity. Delamination may occur around the drilled hole at the top and the bottom of the laminate, corresponding to the hole entry and exit. The hole exit delamination (or push-out delamination) is generally more serious than the hole entry delamination (or peel-up delamination) [12].

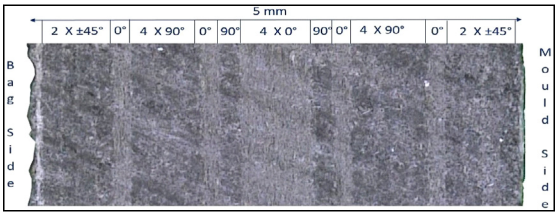

Fig. 1. Sequence of layers in the sectioned CFRP laminate.

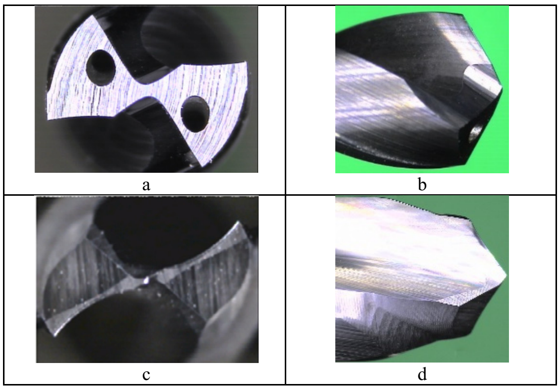

Fig. 2. (a) Traditional tool front view; (b) Traditional tool side view; (c) Innovative tool front view; (d) Innovative tool side view.

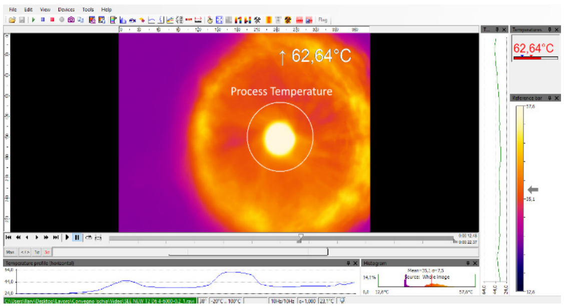

Fig. 3: Optris PI Connect software interface.

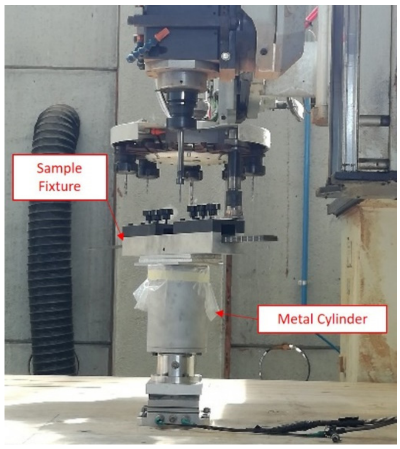

Fig. 4. Drill press equipment.