ACTS3D (ADVANCED CTS IN 3D) TOWARDS DEFECT-FREE MANUFACTURE OF 3D COMPLEX COMPOSITES

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1 Introduction

Automated Fibre Placement (AFP) is known as the state-of-the-art automated manufacturing technology for producing complex composite parts. However, there are still several challenges in manufacturing complex parts of high quality. The complexity could be on either geometry or fibre paths or on both. Typically, complex geometry (e.g. doubly-curved surface) cannot be perfectly tessellated with finite width tapes, therefore the only way for the modern AFP machines to avoid overlaps is to drop tows and control the bandwidth of the tows laid at once, producing characteristic triangle-shaped gaps in the lay-up [1]. In the worst case, the gap may not be closed by the adjacent tows if the required gap is smaller than the width of a single tow. Furthermore, such complex geometry cannot be tessellated by only using tows following geodesic paths; tow steering is normally required. It is well known that tow-steering in the AFP process generates defects such as tow buckling and pull-up [2]. The most challenging case arises when a tow-steered (or fibre-steered) design is implemented in a complex geometry structure for its performance improvement, which could lead to a non-manufacturable part.
Continuous Tow Shearing (CTS) was developed as a solution to overcome the fundamental limitations of the modern AFP machines in tow steering [3,4]. It successfully demonstrated defect-free tow steering by utilising the in-plane shear deformation of the tow material. However, such high-quality steering was possible only when the tow paths were simply shifted along a single direction on a flat surface. Its capability was still limited to address the manufacturing challenges in production of 3D complex structures.

In this work, a significant advancement of the CTS technology was achieved by developing a new CTS head control algorithm realising the continuous tow shearing on three dimensional doubly-curved surfaces as well as a novel tow width control mechanism. The advanced capability of the ACTS3D (Advanced CTS in 3D) process was demonstrated by producing defect-free fibre-steered layers on a doubly-curved complex surface, and its advanced tow steering quality and accuracy were experimentally evaluated.

2 Advanced CTS for 3D fibre steering

The ACTS3D process was realised by combining 3D CTS head control algorithm and the TWiC (Tow Width Control) mechanism. These two advanced functionalities allowed for defect-free steering of a variable width tow following non-geodesic paths on a doubly-curved surface.

2.1 Tow Width Control (TWiC)

The tow width control device was developed and implemented in the CTS prototype head. The original CTS prototype head equips an in-line impregnation module which impregnates the incoming dry tow with an epoxy resin film tape. The TWiC device was developed as an add-on module replacing the original impregnation device to actively control the cross-sectional aspect ratio of the impregnated tow. This novel device allows for producing a variable width tow on the fly.

2.2 3D CTS head control algorithm

The new head control algorithm was based on a new method of tessellating 3D surfaces. The new method considers two guide curves on the target surface as inputs, and creates interpolated curves, which are used to define the edges of the individual tows, considering the nominal tow width. Then all curves on the surface are segmented with a predefined discretisation length, and a pair of adjacent curves forms a tessellated tow, which is like a pin-jointed strip with varying width elements. After tessellating the entire target surface, the tow width elements were extracted and used to calculate the local head coordinates, orientations and widths.

2.3 System integration

The CTS prototype head was mounted on an industrial robot (IRB6640, ABB), and the interfaces between the robot controller and the CTS head PLC controller were established. When the robot code was generated based on the 3D CTS head control algorithm, the local tow widths were mapped to the head coordinates, and the PLC controller controlled the TWiC device by receiving the inputs from the robot controller.

3 Steering test on a doubly-curved surface

The steering trial was carried out on a doubly-curved surface with a negative Gaussian curvature shown in Fig. 1. As shown in the figure, the widths at both ends of the layer were different; the right end was wider than the left end in the figure. The tow edges created by interpolating the two input guide curves and the robot code was generated as described in Section 2.2 and 2.3. A 24K dry carbon fibre tow (IMS65, TohoTenax) was impregnated with an epoxy resin film tape (MTM49-3, Solvay) passing through the TWiC device within the CTS head, which was controlled by the robot controller on the fly to vary the tow width along the paths and avoid tow gaps and overlaps.

4 Result

If AFP process is used to produce the same preform, the left end of the preform must be full of tow overlaps. However, as shown in Fig. 2, there was no overlaps in the ACTS3D lay-up. Furthermore, the basic principle of continuous tow shearing mechanism allowed for eliminating any tow buckling despite small steering radii along the paths. The lay-up accuracy and the thickness variation due to the tow width control were measured using a 3D laser scanner and compared with the intended lay-up design.

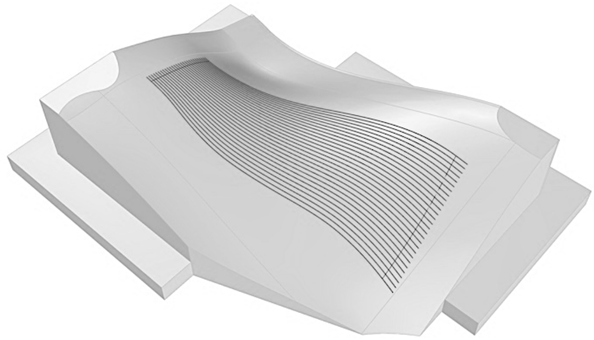

Fig. 1 Tow edges defined on a doubly-curved surface

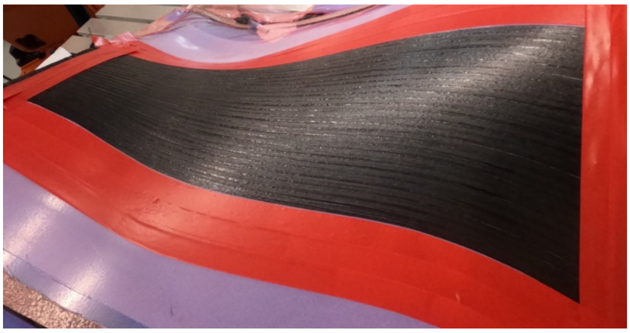

Fig. 2 Defect-free ACTS3D lay-up on the doubly-curved surface.

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