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FIBRE-STEERED FORMING TECHNOLOGY FOR HIGH-VOLUME PRODUCTION OF COMPLEX COMPOSITE COMPONENTS

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ABSTRACT

The automated fibre placement (AFP) process has been widely used to produce large and complex composite aerostructures, and is attracting attention from other industries as a solution for automating manual lay-up processes to improve the quality and productivity. Furthermore, it enables fibre-steered designs with structural performance superior to straight fibre designs. However, when the part geometry is small and highly complex, the advantages offered by AFP cannot be realised. As the lay-up paths become too short to accelerate the head, the machine can never reach its maximum lay-up speed. And the geometry would require fibre-steering with tight steering radii, which results in defects such as tape buckling, gaps, and overlaps. This is a significant challenge in enhancing the automation level in composites manufacturing and realising novel fibre-steering concepts.

In this work, a novel automated manufacturing technology for high-volume production of small and highly complex composite parts was developed by combining three cutting-edge technologies (material, manufacturing, simulation) developed in the Bristol Composites Institute. As shown in Figure 1, the Fibre-Steered Forming (FSF) technology developed starts from designing a flat fibre-steered preform through a Virtual Unforming simulation. In this simulation, from a target 3D preform as an input, a flat preform pattern with fibre steering paths, which can be turned into the target 3D fibre paths after forming, is obtained by reversely forming the target preform. The flat fibre-steered preform is produced by CTS (Continuous Tow Shearing) process and then formed into the target shape using a double-diaphragm forming process. The FSF process works for both continuous fibre prepregs and highly-aligned short fibre prepregs produced by HiPerDiF (high performance discontinuous fibre) process, and its feasibility and production qualities were compared numerically and experimentally.

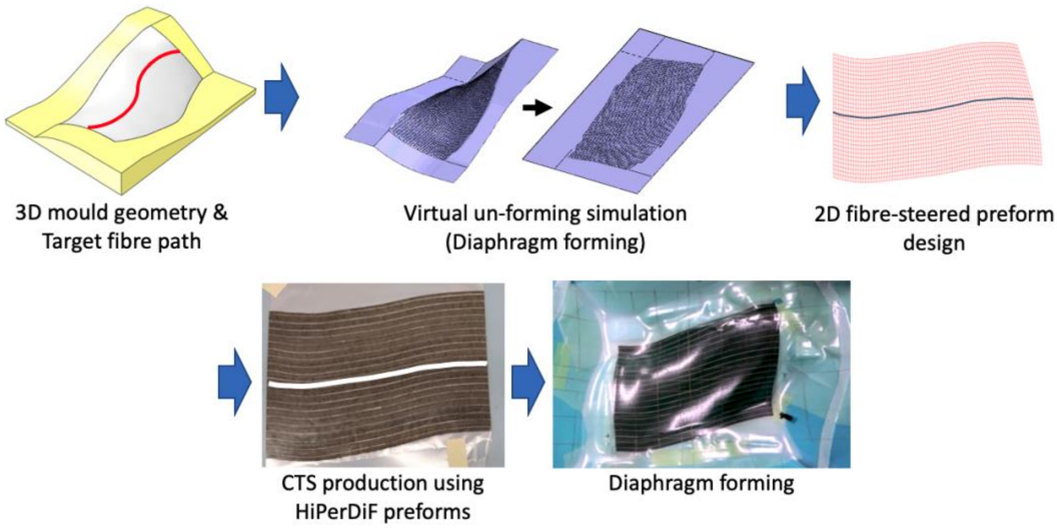


Figure 1: Process flow of the Fibre-Steered Forming Technology.

The Virtual Unforming was realised by directly reversing the forming process. An initial double-diaphragm forming simulation was first performed with a surrogate preform model with simplified material properties to extract the nodal displacement histories of the diaphragm models. Then an as-designed 3D preform model with target fibre paths was replaced with the surrogate model, and the nodal displacement histories were reversed to deform the diaphragms back to the original flat states [1]. A hybrid element, which is a shell element superimposed with a membrane element, was used to represent out-of-plane bending and in-plane material properties of the preform, respectively. Figure 2 shows the overall process of deriving a representative fibre path from the 3D target preform. After the unforming simulation, 100 mm wide carbon/epoxy prepreg tapes were steered along the representative path using the CTS process to produce the 2D fibre steered preform, as shown in Figure 3 (a) [2]. The produced preform was formed in a bespoke double-diaphragm forming rig, and the forming quality of the preform on a doubly-curved complex surface was analysed using a 3D coordinate measurement system. HiPerDiF tapes were tested in the same test framework. HiPerDiF tapes made with 3 mm long carbon fibres were used to produce fibre-steered preforms and their formability on a complex geometry tool was assessed comparatively with the continuous fibre steered preform. As shown in Figure 3 (b), it was found that the stretchability of the HiPerDiF preform offered superior formability over the continuous fibre preform.

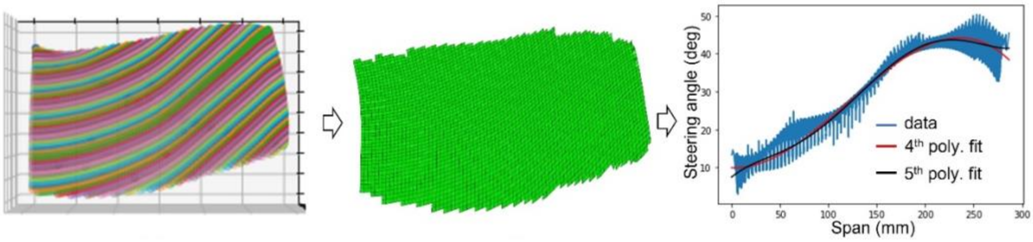
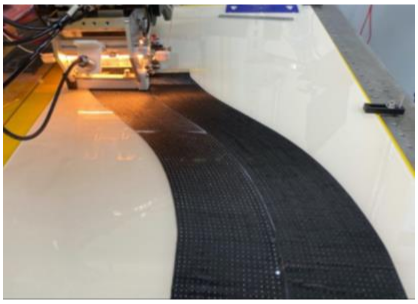


Figure 2: Overall process of deriving steering fibre path: (left) 3D ‘as-designed’ fibre orientation in code framework, (middle) 2D flattened preform after the ‘un-forming’ simulation, (right) averaged fibre angle variation along the span for CTS production.

(a)



(b)

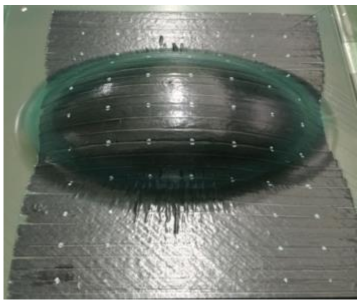


Figure 3: (a) Fibre-steered preform production using CTS process, (b) a single ply HiPerDiF preform formed on a doubly-curved surface.

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