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Manual 2-dimensional Fabric Steering, for the Manufacture of Variable Stiffness Panels

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Abstract

In recent years, Automated Fibre Placement has been applied in manufacturing variable stiffness panels containing continuously changing fibre paths. The aim is to achieve superior mechanical properties, compared to straight-fibre laminates [1,2]. This paper proposes a novel low-cost manufacturing technique, referred to here as 'manual 2D fabric steering'. The process is able to manufacture similar variable stiffness panels to those produced using Automated Fibre Placement. By manipulating biaxial fabrics, curvilinear fibre paths can be created. The technique involves very low equipment costs and can be used to steer multiple-layers of fabrics simultaneously (in contrast to the tow-by-tow and layer-by-layer fibre deposition method in Automated Fibre Placement), leading to faster production rates and lower costs, at least for smaller production runs. A computer aided engineering tool, SteerFab [3], is used to guide the design and manufacture process by predicting: (a) the optimum 2D fibre paths, (b) the subsequent mechanical behaviour of the resulting variable stiffness panel (including improvements in buckling resistance) and (c), the step-by-step instructions for the actual manufacturing process. In this paper, manual 2D fabric steering is described and the effect of the manipulation sequence on the final steered fabric preform is investigated. The repeatability of the process is also examined.

Keywords: 2D Forming; Fabric steering; Curvilinear fibre

1. Introduction

In recent years, variable stiffness panels have drawn much attention because they offer improved buckling resistance and post-buckling properties by using continuously changing fibre angles, compared with more traditional straight-fibre laminates that have fixed fibre angles (e.g. 0°, 90°, ±45°) [1,2]. Automated fibre placement (AFP) is the usual technology for manufacturing variable stiffness panels in aerospace industry [4-6]. The process steers individual fibre tows and deposits them on a mould. However, the complicated fibre placement head and fibre delivery system, together with the associated AFP robot, bring high capital costs. Additionally, the tow-scale fibre deposition method limits the production rate and can lead to process-related defects such as gaps and overlaps in the resulting laminate [2,6,7].

Preforming of engineering fabrics for subsequent liquid moulding is a viable manufacturing process for high-volume production, partly because multiple layers of fabric can be formed in a single step [8]. In order to improve production rate and avoid the requirement for expensive capital investment, this investigation proposes a novel technology to manufacture steered-fibre fabric preforms using a novel approach, referred to here as 'manual 2D fabric steering'. Previously, a numerical design and analysis tool, SteerFab [3], was developed to predict steered fibre patterns with optimised mechanical properties. According to [3], the buckling properties of the steered-fibre laminates can be improved by approximate 10%, compared to quasi-isotropic straight-fibre laminates. In this paper, SteerFab it is used to guide the manual 2-D fabric steering process in lab-based experiments, in order to investigate how processing factors affect the final steering results.

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2. Methodology

In [3], a computer aided engineering tool, SteerFab, was reported, developed for design and mechanical property optimisation of steered fibre laminates. Using SteerFab, both the steered pattern and the corresponding initial unsteered shape can be created, as shown in Figure 1.

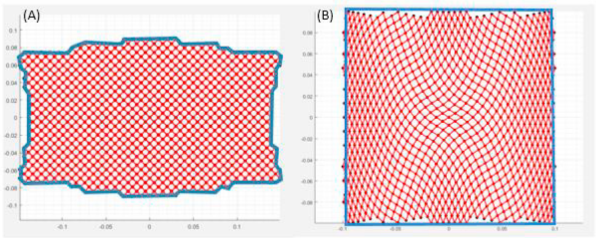


Fig. 1. Initial unsheared shape (A); The corresponding steered pattern (B); generated by SteerFab code.

An initial manual forming trial inspired the proposed manufacturing process (see Figure 2) resulting in a short feasibility study [9]. A plain-woven glass-fibre fabric was deformed by hand and its perimeter was fixed using G-clamps to generate non-linear fibre paths.

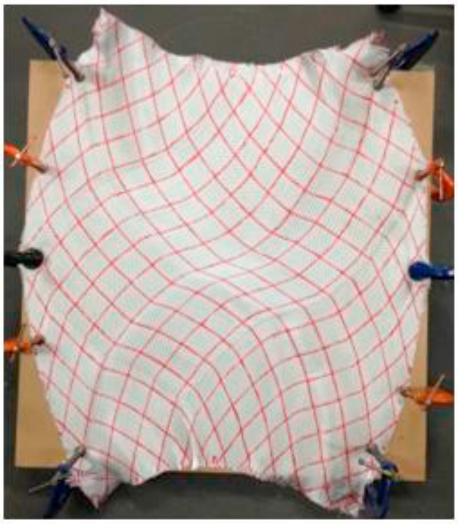


Fig. 2. Initial manual steering forming trial to create curvilinear fibre path

However, manipulating just the fabric perimeter places constraints on the complexity of the resulting steered pattern that can be manufactured and lacks accurate practical control of fibre directions across the inner region of the fabric. An alternative method, capable of controlling the positions of an arbitrary number of 'manipulation control points' across the whole area of the fabric was devised. The first step involves using SteerFab to provide details of the initial and final target positions of manipulation control points across the fabric, before and after deformation. The computer cursor can be employed to select nodes within a user-defined polygonal area to show the initial (blue dot) and final (black dot) positions, see Figure 3.

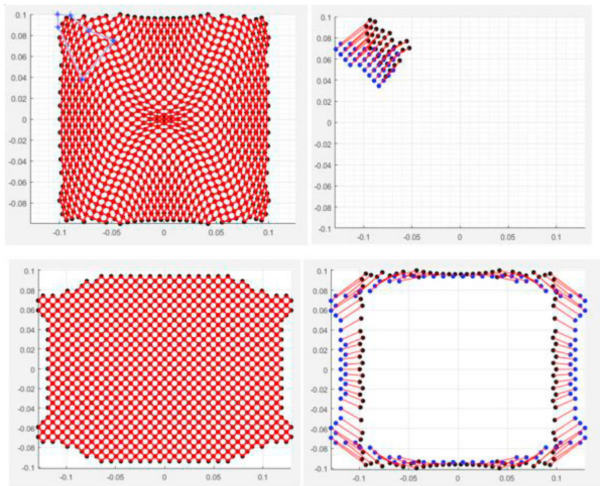


Fig. 3. Examples of using the 2-D forming function in the SteerFab code

To replicate this technique in practice, nylon fishing line was used to pierce selected points of the undeformed fabric at selected manipulation control points. To solve the potential problem of fabric damage due to concentrated loading by the threaded line, buttons were used to reduce stress concentrations. Figure 4 schematically shows the detailed threaded structure. The nylon line was also threaded through holes drilled in a Perspex sheet; the position of these holes corresponded with the final positions of the associated nodes on the final target steered fibre pattern. By pulling the threads into places, steered fabric sheets are manufactured.

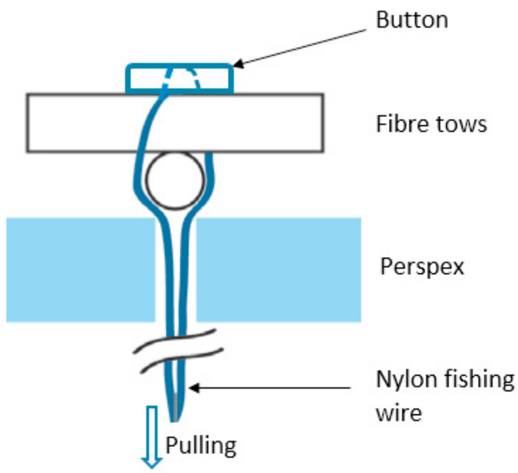


Fig. 4. Examples of using the 2-D forming function in the SteerFab code

This 2-D forming process prompts 3 important questions for optimum manufacture: (1) how to best select control points; (2) what is the repeatability of the process and (3) does the manipulation order affect the final steered pattern and the generation of forming defects (e.g. out-of-plane wrinkling). An goal of the multi-point manipulation manufacture process is to achieve the steered fibre pattern as closely as possible, without defects, and ideally without using any manual hand manipulation.

To answer these questions, two experiments were conducted to understand both process repeatability and the effect of manipulation order. In both experiments, the steered pattern predicted by the kinematic model was divided into a 5 x 5 grid, with a control point at each corner and the nodes were numbered, as shown in Figure 5A and 5B. The SteerFab code predicted the initial and final positions of the control points (Figure 5C). The initial positions were marked on the fabrics for button threading and holes were drilled in a Perspex sheet based at the final positions. A plain woven glass fibre fabric (ECK 10 – 300gsm from Allscot) was used to conduct these two experiments. Each sample for steering was in the form of two aligned fabric sheets, and a thin layer of adhesive (3M Spray Mount) was applied between the two sheets to improve integrity and reduce potential damage caused by pulling the nylon lines.

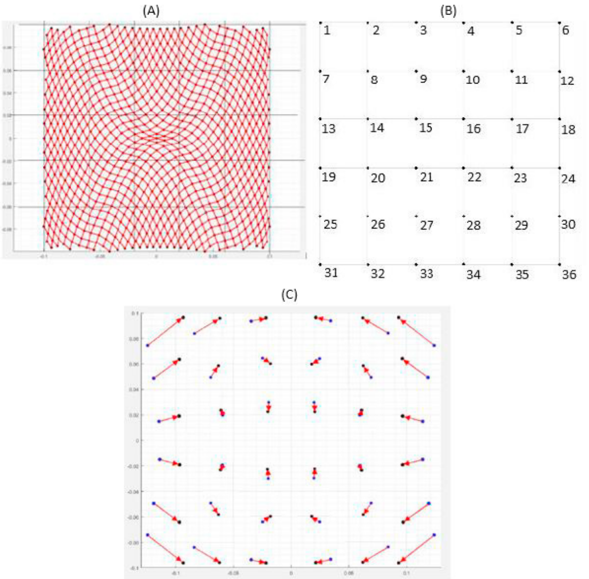
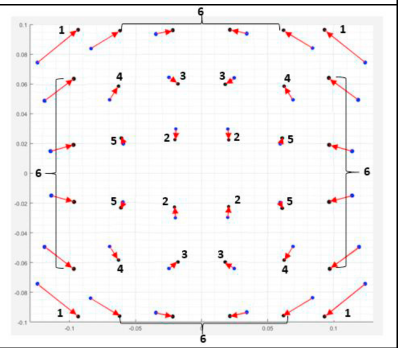
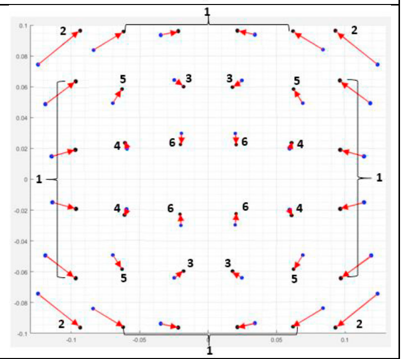
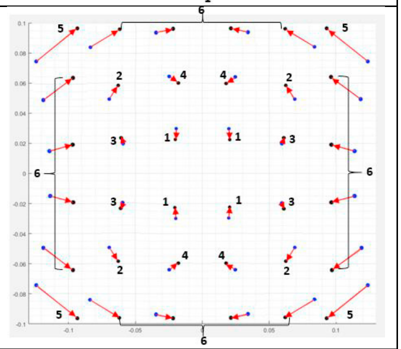


Fig. 5. The control points selection (A); The numbering (B); and The initial (blue) and final positions (black) of the points selected (C).

In the repeatability experiment, a manipulation order (Order 1 in Table 1) was selected. This test was repeated three times. A picture of the fabric was taken after each manipulation step to compare whether the shape of the fabric is the same in each repeat. To investigate the effect of manipulation order on the final pattern, three different orders were studied. The details of each order are also listed in Table 1.

Table 1. The investigated manipulation orders and the corresponding schematics.

Order No.	Order description	Schematics (Numbers indicate sequence)
1	Outside corners → Centre → Towards outside	
2	Outside perimeter → Towards centre	
3	Centre → Perimeter (Completely reverse order of Order 2)	

3. Results and Discussions

Figure 6 shows the final steered patterns of the three samples using the identical manipulation order (Order 1 in Table 1). The patterns look similar and the locations of wrinkles created by the manipulation are the same. The shape of the samples at each manipulation step are also similar. This indicates that this process has good repeatability.

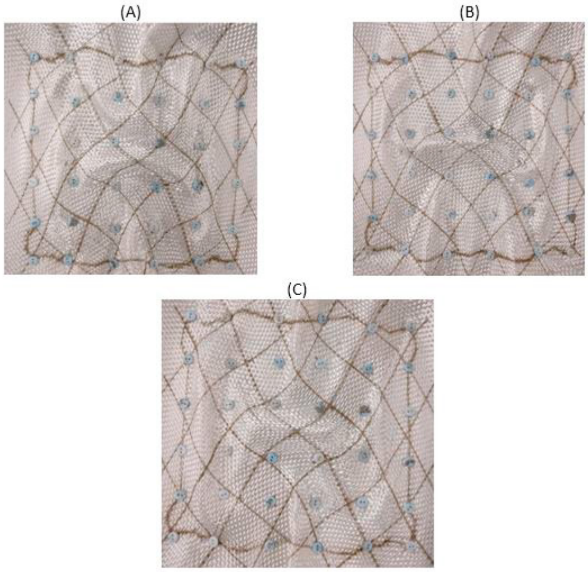


Fig. 6. Final steered patterns created by using Order 1: sample 1 (A); sample 2 (B); sample 3 (C)

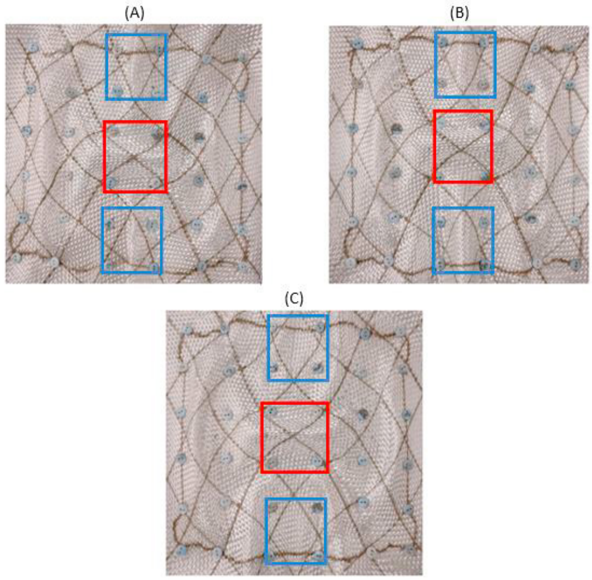


Fig. 7. Final steered patterns created by using Order 1 (A); Order 2 (B); and Order 3 (C)

Figure 7 shows the steered patterns created by the three manipulation orders. There is no major difference between the patterns created by Order 1 and Order 2 (Figure 7A and 7B). However, when comparing the patterns created by completely reverse orders (Figures 7B and 7C), one distinct difference is the presence of the wrinkles in the blue regions. The reason for this is the development of wrinkles during the manipulation process. The Figure 8 shows that after the 1st manipulation, Order 2 has formed a large wrinkle at the vertical centreline. Because the displacements of the points within the blue box regions cannot provide sufficient tension to eliminate the wrinkles, once the wrinkles have formed, they will exist to the final state. In contrast, the manipulations in Order 3 did not give the fabric a chance to form the wrinkles along the vertical centreline. The wrinkles indicated inside the red box exist in all the specimens, irrespective of the order. This is because the displacements of the four points within the red region are all directed towards the centre of the steered fibre pattern, so the fabric is under compression (though alternative choice of control points could potentially solve this issue).

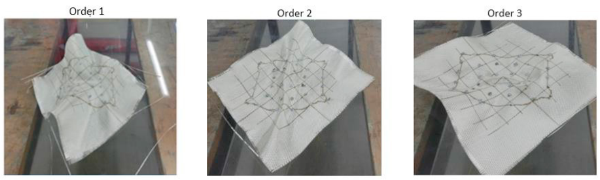


Fig. 8. The morphology of the fabrics at the 1st step manipulation using Order1, Order 2, and Order 3

Based on the results above, there appear to be at least two techniques to reduce wrinkles during 2-D forming:

- Avoid large-scale wrinkles generated early in the forming stage. The specific method to do this is to manipulate control points having the smallest displacements first to constrain the fabric, so that the later manipulations are less likely to introduce wrinkles.
- Select control points which apply tension to the fabric during their displacements.

Additionally, in [10], the authors demonstrated how Perspex sheet could be used to mitigate wrinkles in the uniaxial bias extension. The same concept can be applied in this fabric steering process. During 2-D fibre steering, the fabric is placed between the workbench surface and a Perspex sheet. Weights are also placed on the Perspex sheet to add extra pressure in the normal direction. The schematic of the set-up is shown in Figure 9.

Fig. 9. Schematic of surface constrain set-up to eliminate wrinkles

Using this improved understanding of the 2-D fabric steering process, both a plain woven glass-fibre fabric (ECK 10 from Allscot) and a 2/2 twill woven carbon fibre fabric (CF-22-20 from Easy Composites) were preformed into steered sheets. Figure 10 shows a good match between the steered pattern predicted by SteerFab and the fibre-steered fabrics manufactured in the lab.

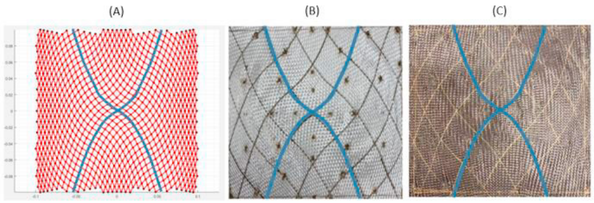


Fig. 10. Schematic of surface constrain set-up to eliminate wrinkles

4. Conclusions

A novel process, 2-D fabric steering, has been developed in order to manufacture steered fibre preforms. Currently the process involves a good deal of manual preparation and handling and but has the capability to steer multiple layers of fabrics in one preforming step (increasing speed) and has very low equipment costs. The technique demonstrates good repeatability though the ordering of the manipulation process significantly influences the final results. In order to eliminate wrinkles generated during processing, in addition to applying a surface constraint, the selected manipulation points should ideally induce tension in the fabric during their displacements and manipulation control points having the smallest displacement should be manipulated first. Initial experiments show 2-D fabric steering can be successfully sued to manufacture steered patterns created in the SteerFab code.

Acknowledgements

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