Advanced Automated Tape Laying with Fibre Steering Capability Using Continuous Tow Shearing Mechanism

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Advancements in material science have enabled the aerospace industry to leap forward, and in the never ending quest for lighter, stronger and stiffer materials composites are leading the race. Extensive usage of composites in modern aircraft has led to reductions in fuel consumption by up to 25% and thus to significant environmental and economic benefits. However, further improvement is challenging with current design practices, which dictate that composites are designed and manufactured in layers of straight fibres.

Recently, a composites design approach, which optimally distributes the structural loads through curvilinear fibre paths, in order to improve the structural efficiency of modern aircraft, is gaining attention thanks to advances in automated fibre placement technologies [1]. For example, a composite wing skin with optimally steered fibre paths could distribute the load directly onto the wing stiffeners and thus achieve a significant weight reduction, while maintaining the same stiffness and strength (Figure 1) [2]. Also as the fibre steering designs make it possible to tailor the stiffness of a structure locally, they allow for aeroelastic tailoring of aircraft structures [3]; an area which could play a vital role in the future, as more flexible wings are under consideration for future aircraft programs. Overall, fibre steering can significantly expand the design and manufacturing space for composite structures, allowing for more radical and optimised designs and shapes that were not possible before.

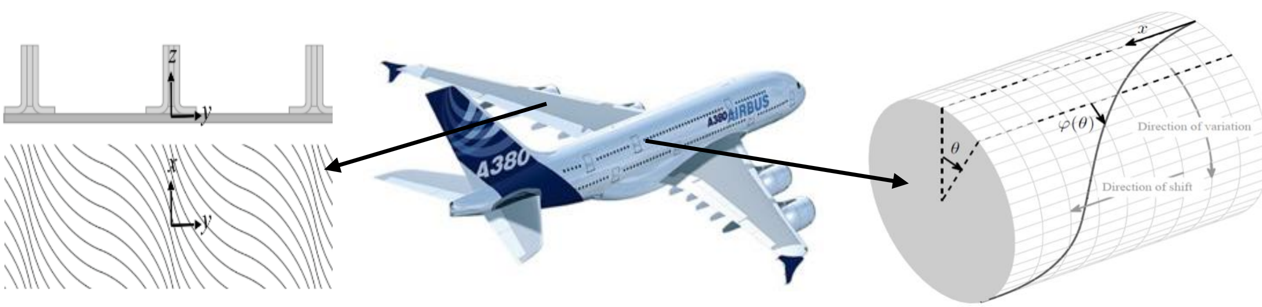


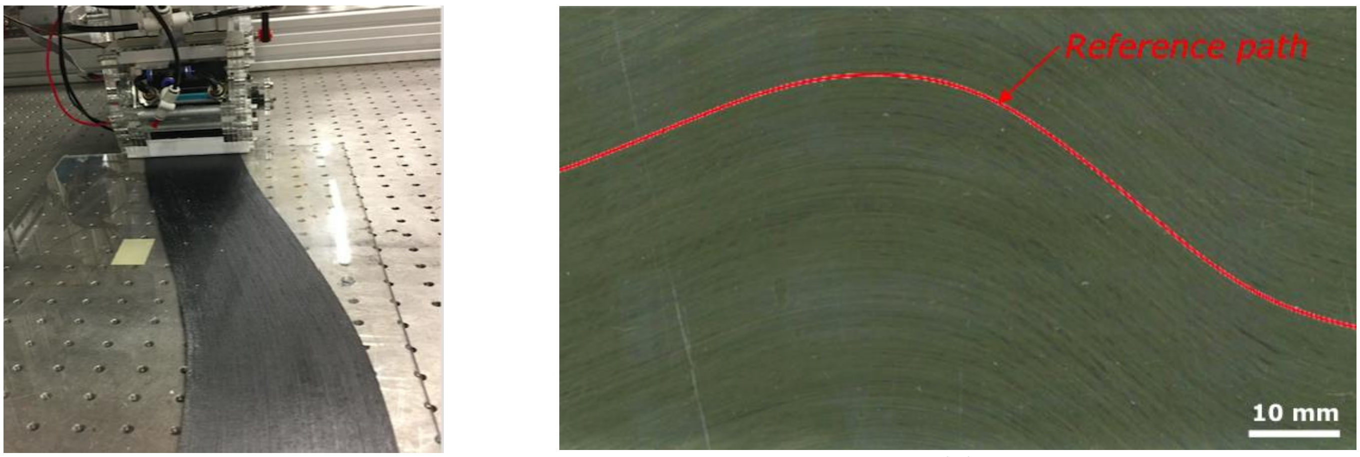
Figure 1. Example of a fibre steered design of a wing skin and a fuselage section

The current state-of-the-art technology enabling such designs is the automated material placement process, where carbon fibre tapes are laid up on a mould surface using a robotic material deposition head. However, although these machines are excellent at laying straight paths, their fibre steering capabilities are extremely limited. The reason is that they bend the tapes in order to steer the fibre paths, which inevitably leads to significant defects such as fibre buckling and resin pockets. Furthermore, as the minimum steering radius is dependent on the tape width, the automated tape laying machines laying more than 100 mm wide tapes have almost no steering capability.

In order to address this manufacturing issue, a novel fibre steering concept, named Continuous Tow Shearing (CTS), was developed at the University of Bristol [4-6]. The CTS can align fibres along a curved path without causing buckling and defects, by shearing continuously-fed tapes. The main advantage of this technology is, that since it relies on the shear deformation of the tape, the material width no longer affects the minimum steering radius, meaning that much wider tapes can be employed, significantly boosting the productivity of the process. In order to assess the performance of this technology, a lab-based CTS head was developed that can place up to 100 mm wide unidirectional prepreg tapes (Figure 2).

In this research, the process parameters affecting the prepreg shearing quality were identified. It was found that fibre tension, temperature and shear rate affect the lay-up quality that can be achieved with the process. To enable control of the fibre tension while shearing, a tape tension control mechanism was implemented in the head module. The lay-up tests were carried out by laying up 100 mm wide prepreg tapes following paths with different steering radii and maximum shear angles as well as at different shear rates. The preliminary experimental results revealed that the lay-up quality was mainly dependent on the shear rate and angle. In order to quantify the quality of the fibre steering, the in-plane wrinkling was measured using image analysis, while the out-of-plane wrinkling and surface roughness were measured using a 3d surface scanning method.

From the test results, it was validated that the CTS process could reach a minimum steering radius as low as 50 mm for an 100 mm wide prepreg tape without significant defects. This steering radius is an order of magnitude lower compared to the state-of-the-art commercial placement machines, where it is approximately 4000 mm for machines which use 100 mm wide tapes, and 650 mm for machines which use multiple 6.35 mm wide tows. CTS then is a technology that allows for wide tape layup with steering capabilities, something which was not possible before. Most notably however, since it drastically expands the design space for composites, it is a technology that can shape the next generation of ultra-efficient aircraft.



(a) (b)

Figure 2. CTS of a 100 mm wide prepreg tape; (a) Prototype head, (b) Continuously sheared prepreg specimen after curing.

References

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