Optimization of Tow Steered Fibre Orientation Using the Level Set Method

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Carbon Fibre laminates are highly orthotropic materials, which have significantly greater stiffness in the direction that the fibres are orientated then the direction perpendicular to the fibre. It is well know that the best performance from carbon fibre structures is achieved by orientating the fibres to line up with the principal strains experienced by the structure under common loading conditions. The common practice is to use multiple layers of straight fibre laminates to account for multiple loading environments.

Tow steering robotic carbon fibre manufacturing machines have enabled a step change in carbon fibre component performance. These machines can lay down carbon fibre tows in curved and continuously varying paths, allowing the fibres to be “steered” into different orientations in different regions of a single or multiple layer structure. This offers a potential for the fibres to be better tailored for complex loading environments and significantly improve the overall structural efficiency.

This paper introduces a new method to optimise the continuously varying angle fibre orientation using the level set method. The level set method is a flexible boundary representation method that has seen success in topology optimisation. An advantage of using the level set method is that the design variables remain continuous even with drastic changes in the boundary.

The proposed method uses a level set method to represent the carbon fibre tows in a mechanically loaded structure. An implicit signed distance function stored at the finite element nodes is used to define the location of the curved fibres. Local optimization sensitivities will be used to iteratively update the implicit level set function in order to change the fibre orientation to minimize the overall compliance. The primary advantage of this method is that due to the continuous nature of the level set function, the convergence is favourable and an optimum solution can be obtained reliably. We will demonstrate the proposed method by optimizing the fibre orientations in a plate model under both in plane and out of plane loading.

The method will also be used to design a tow steered carbon fibre intertank plate structure for the space shuttle, where the solid rocket boosters attached to the external fuel tank. The objective is to orientate the carbon fibre tow paths to distribute the large point loads from the solid rocket boaster so that the load at the base line of the plate is approximately uniform. A more even distribution of the applied load throughout the structure will reduce the need for local reinforcement around the load application point and hence enable a reduction in the structural weight.