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Modeling of Process-Induced Deformations in In-Situ AFP Manufacturing of Thermoplastic Composites

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ABSTRACT

The Automated Fiber Placement (AFP) process offers a new approach to manufacture of large complex composite structures compared to traditional manufacturing techniques. The AFP process involves the deposition of composite tapes layer by layer onto a tool surface, with the ability to produce both thermoset and thermoplastic composites. The advantages of the AFP process over traditional techniques include a reduction in material waste and an increased deposition rate. A unique advantage of thermoplastic composites is the ability to consolidate in-situ, which can be achieved by the AFP process alone, eliminating secondary processes such as autoclave treatments, resulting in significant manufacturing cost/energy savings. The in-situ production of thermoplastic composites using the AFP process consists of a heating, consolidation and solidification step. During the heating step, the incoming tape (a flexible combination of fiber and matrix) is heated to a temperature above the melting point of the thermoplastic matrix. The consolidation step then follows, whereby the tape undergoes deformation, resulting in contact between the tape and the substrate, which is facilitated by the compaction roller.

However, the processing of thermoplastic composites using AFP in-situ consolidation has still technical challenges and process difficulties. One of those challenges is that structures characterized by free edges, including flat panels and curved shells, undergo distortion during and after in-situ AFP processing. This process-induced deformation and stress are two of the most challenging issues in in-situ AFP processing of thermoplastic composite structures. A key aspect in the design and optimization of the AFP process is the modelling of the process to understand and predict the formation of process-induced residual deformations.

In this work, a methodology is proposed for estimating the different residual strains – also called Eigenstrains – caused during in-situ manufacturing that lead to process-induced deformation. The methodology addresses multiphysics aspects of in-situ manufacturing of thermoplastic composites made by AFP. To this end, the thermal and mechanical behavior is described by a series of simulations, which are to be carried out in sequence. Initially, a decoupled thermomechanical analysis is performed sequentially on a representative mesoscale model. The strains are then extracted and transferred to a global model of the entire part to calculate its distortion. This facilitates more precise control and understanding of the AFP manufacturing process. Of particular interest is the identification of the various strains that emerge during the manufacturing process and are responsible for the process-induced deformations.