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Simulation based optimization on automated fibre placement process

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Abstract. In this paper, a software simulation (Autodesk TruPlan & TruFiber) based method is proposed to optimize the automate fibre placement (AFP) process. Different types of manufacturability analysis are introduced to predict potential defects. Advanced fibre path generation algorithms are compared with respect to geometrically different parts. Major manufacturing data have been taken into consideration prior to the tool paths generation to achieve high success rate of manufacturing.

1. Introduction

Automated fibre placement (AFP) technique is widely applied on composites automated manufacturing field. The problems followed, however, are critical when compared to traditional handcraft. Experimental studies[1] proved the necessity of the application of the manufacturing system upgraded with simulation tools. Autodesk TruPlan is based on multiple advance optimization algorithms and assesses the cost-impact of unique design features and surface definitions across multiple manufacturing processes, such as: Automated Fiber Placement (AFP), Automated Tape Laying (ATL), Hand Layup (HLU) or any combination of these strategies. This study focuses on the AFP process and the statistical data necessary to evaluate the impact of various design concepts against various manufacturing processes. Course trajectory propagation algorithms are compared between different shapes of products. Manufacturing feasibility analysis have been carried out to catch common fabrication issues at the early step. Down to the manufacturing stage, numbers of advanced features such as ‘Operation Strategy’ and ‘Process Zone’ have been involved to optimize tool paths.

2. Manufacturability Study

2.1. Propagation Mode

Automated fiber placement technology was invented originally to solve the manufacturing issue of geometrically complex parts due to the presence of tight radii, double curvatures and surface joggles. As a result, various fiber path generation algorithms (i.e., Propagation Mode) need to be taken into consideration and compared to achieve high-quality products. Autodesk TruPlan supports three types of propagation modes, known as ‘Constant Angle’, ‘Constant Angle Offset’, and ‘Guide Curve Offset’, respectively as shown in Figure 1.

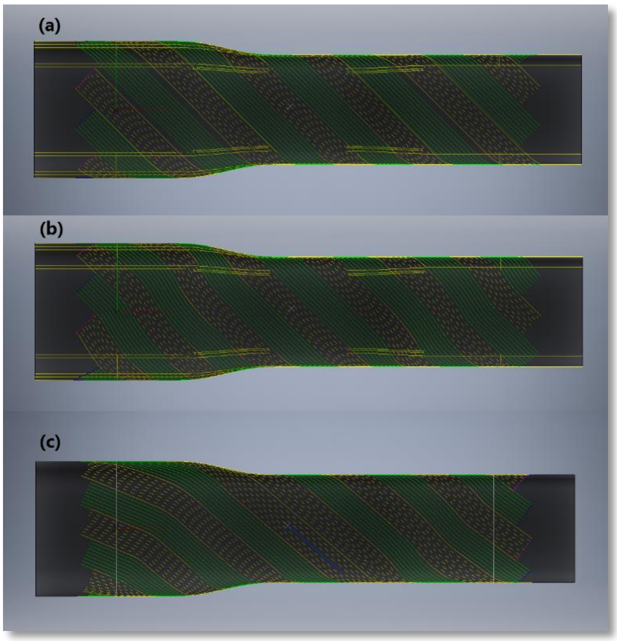

Figure 1. Three types of propagation modes applied on the same spar part: (a) Constant Angle, (b) Constant Angle Offset and (c) Guide Curve Offset.

2.1.1. Constant angle. The Constant Angle propagation mode consists of creating courses whose centreline follows the direction of material specified for the ply as shown in the Figure 2, where 1 is to transfer the rosette onto the surface at the point and 2 is to rotate the projected vector to the ply orientation. In other words, the tangent to the centreline at any point along the centreline is equivalent to the reference vector for the ply projected onto the tangent plane of the support and rotated around the normal to the specified orientation. Constant Angle is propagated to minimize material angle deviation, but cannot control the gap/overlap in between adjacent courses (Figure 1 (a)) very well. So it is recommended to be used on geometrically simple parts.

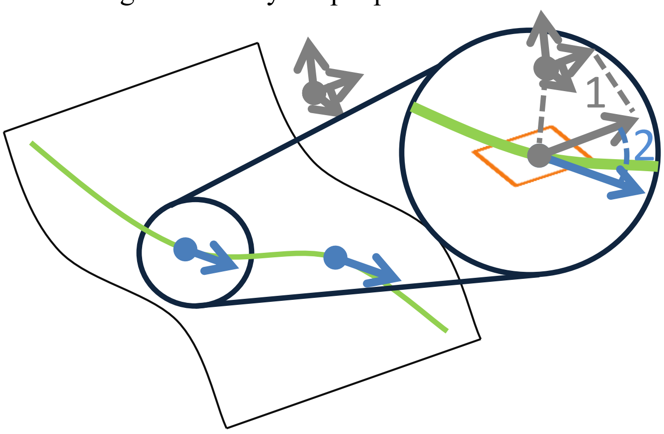

Figure 2. Schematic diagram of the tangent to the centerline at one point.

2.1.2. Constant Angle Offset. The first course generated has a constant angle centreline, following the rule of Constant Angle propagation mode, and other courses are adjacent to the previous course and are parallel offsets of the centreline of the first course. Figure 1 (b) shows the fibre paths generated on spar part, where steering tows will be laid. In spite of this, the tow-steered bands decrease the occurrence of gap or overlap defects, which improves the mechanical properties of the laminates.

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2.1.3. Guide Curve Offset: The Guide Curve Offset propagation mode uses curve geometry (See the short blue line in Figure 1(c)) to create the centreline for the first course. The supplied guide curve is extrapolated using a geodesic curve to the ply or region boundary if it does not span the entire domain of the ply. The remaining courses are generated as parallel offsets of the first course. A well-defined guide curve geometry is a good compensation of the potential deviations of the Constant Angle mode, and meantime the Guide Curve Offset also holds the advantage of Constant Angle Offset in terms of 'offset' to eliminate most gap and overlap defects.

2.2. Manufacturability Analysis

Manufacturability or producibility analysis makes it possible to let composite manufacturers anticipate the costs of fabricating a certain part and also optimize their entire process to avoid re-engineering and downtime on the shop floor. The data collected enables engineers to perform comparative cost-benefit analyses to determine optimum materials, processes, and equipment. Figure 3 shows the six different types of producibility analysis implemented in Autodesk TruPlan to comprehensively predict potential defects during automated fiber placement operation.

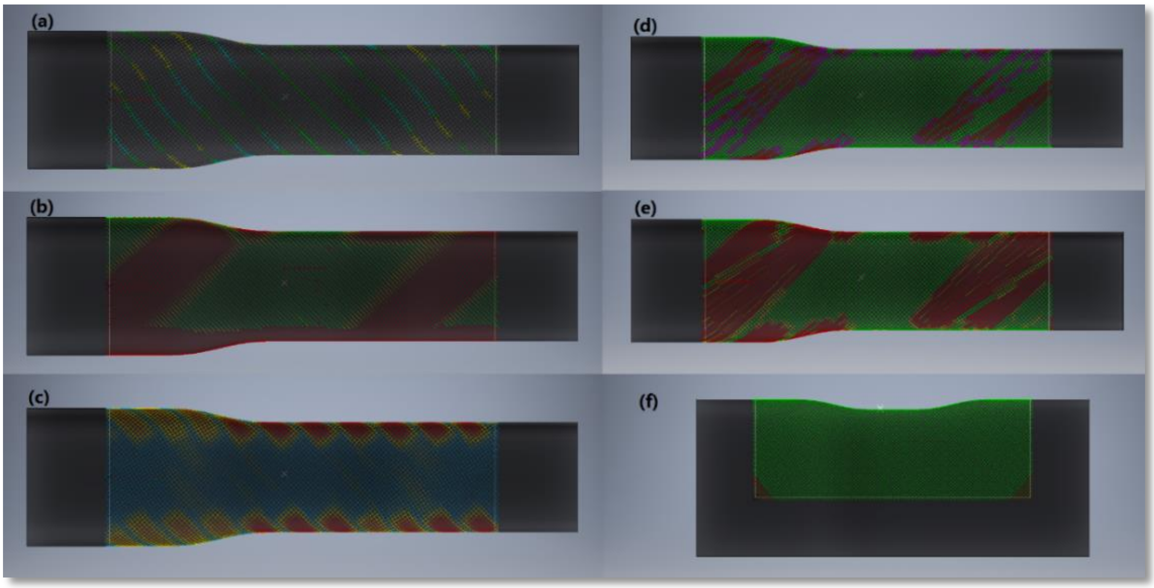

Figure 3. Six types of manufacturability analysis applied on the same spar part: (a) Gap/Overlap, (b) Angle (c) Compaction, (d) Wrinkle, (e) Steering and (f) Tow Length.

2.2.1. Steering. Automated fibre placement was used to optimise the tow steering of carbon fibre reinforced plastic/polymer whereby the minimum defect-free steering radius achievable[2]. In this instance, 1000 mm and 500 mm are set as steering radius warning and limit values, respectively. The most risky area in terms of tow steering is depicted in red in Figure 3 (e). With the simulation results, the laminates designers or the manufacturers can be well guided to fix the defects prior to the physical processing.

2.2.2. Gap/Overlap. Figure 3 (a) shows the results of Gap/Overlap analysis with the settings where the values of gap and overlap warning are ± 0.0254 mm, respectively, and the ones of those limit are ± 0.254 mm.

2.2.3. Angle. Figure 3 (b) simulates the fibre angle deviation results. The warning and limit are set to 1 and 5 degree, respectively.

2.2.4. Compaction. Figure 3 (c) displays analysis results of compacting distance of AFP roller with respect to the substrate. Here the compaction warning and limit are 2 mm and 5 mm, respectively.

2.2.5. Wrinkle. Material wrinkle analysis counts two major parameters: One is shearing angle along width direction and the other is material spreading along length direction. Figure 4 (d) indicates the wrinkle analysis results of this spar part with the settings, where maximum shearing angle is 1 degree and maximum spreading is 3%.

2.2.6. Tow Length. An AFP equipment always has specified allowable tow cut length value due to the limitations of the mechanical structure of the machine head. Tow length analysis consumes the value to find those tows that are too short to cut. As shown in Figure 3 (f), all the tows shorter than 100 mm are displayed in red.

3. Kinematics Optimization

Fiber placement operation is not straightforward to interpret, although the design information has been well collected, since it depends on numbers of factors such as tows laying direction, off-part motion, compacting pressure of AFP roller and feed rates of machine head. Autodesk TruFiber, using data from TruPlan, is designed to optimize multiple processes and generate tool paths with their associated NC codes for manufacturing.

3.1. Operation Strategy

3.1.1. Layup Direction. Typically, there are two types of machine movements need to be eliminated for higher fabrication efficiency: Off-part motion and Head reversing motion. For small parts, unidirectional layup (As shown in Figure 4 (a)) is recommended as the head rotation is much more time-consuming. For big-size parts, however, the off-part motion becomes a big concern due to the long linking path, so the bidirectional strategy (As shown in Figure 4 (b)) is a preferable choice to reverse machine head after completing each fibre course. An optimal 'combined' solution is provided by TruFiber tool to nominate the 'Maximum Unidirectional Length', meaning that any course shorter than the defined value is not reversed, otherwise it goes with bidirectional way. Figure 4 (c) shows the tool paths computed using the 'combined' layup strategy, where the 'Maximum Unidirectional Length' is set to 1000 mm.

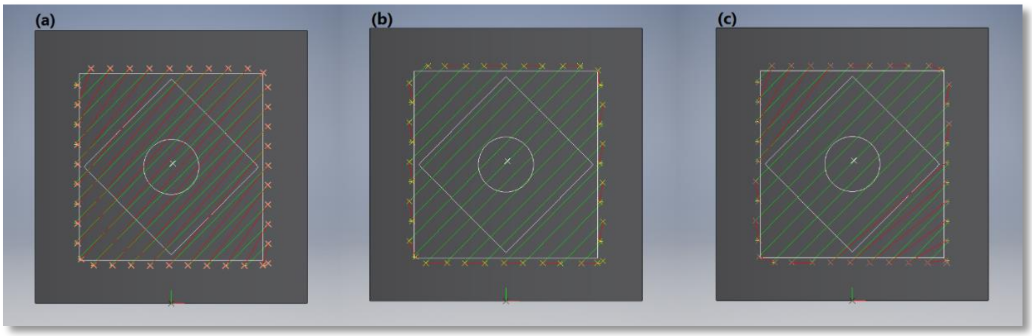

Figure 4. Tool paths computed results using three types of layup direction strategies on the same circle-diamond-square part: (a) Unidirectional layup, (b) Bidirectional layup and (c) Bidirectional with 'Maximum Unidirectional Length'.

3.1.2. Automatically Break Courses. In most cases, the holes have to be first filled with bands (As shown in the centre of Figure 5 (a)) and then be drilled in the trimming process. The best idea is that the courses can be broken when it passes through the holes. Figure 5 (b) illustrates the situation that TruFiber determines to 'Automatically Break Courses' to fly through the hole with the diameter of 400 mm, where the 'minimum course break distance' is set to 200 mm.

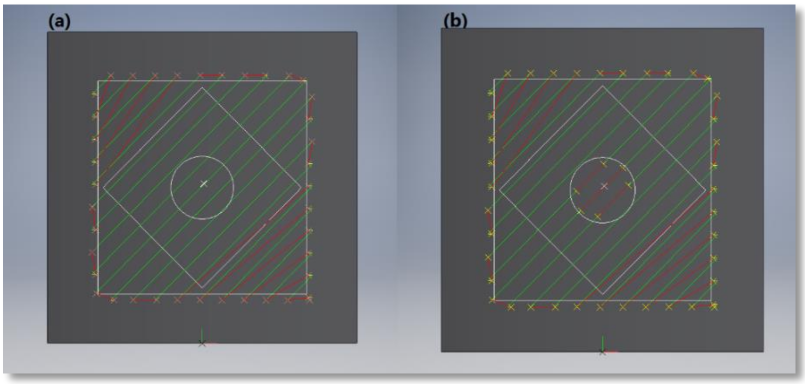

Figure 5. The comparison of tool paths computed results between (a) 'Automatically Break Courses' disabled and (b) 'Automatically Break Courses' enabled.

3.2. Process Zone
A Process Zone is an area to use specific manufacturing parameters appropriate for the characteristics of that area. For example, when a roller is being applied to a ramped surface, a lighter compaction force is desired so as not to crush the underlying surface at the start of the ramp, or to use over-feeding to make sure there are no gaps between the material and the surface. In this case, a zone for the ramp can be created as shown in the Figure 6 (The region in between the two blue contours).

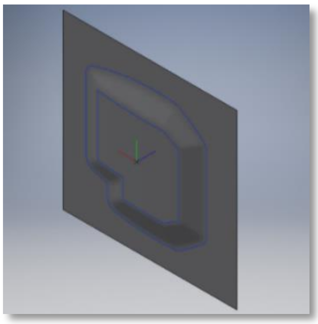

Figure 6. Process Zone defined on the ramp surface of the engine cover part.

4. Conclusion
Current research status concerning automated fibre placement process and related equipment has been reviewed. The results imply the requirement of the advanced system equipped with simulation software to optimize the design and manufacturing lifecycle. Autodesk TruPlan, as a result, is introduced to conduct course propagation and analysis to assess the manufacturability of unique design features and surface definitions. Another software tool (Autodesk TruFiber) is proposed to optimize the fibre placement operation from kinematics point of view.

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