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In-process detection and automatic response to AFP deposition defects

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ABSTRACT

While automation of composites manufacturing processes has been successfully industrialised, inspection and re-work can take as much as 40% of the value-adding steps [1]. Defected components are rejected, leading to waste as well as more time for reworking. To address these issues, we have developed a new, highly-instrumented, and finely-controlled research-based automated fibre placement (AFP) deposition system that exceeds the measurement capability of current industrial machines. This testbench is referred to as the real-time automated fibre placement (RT-AFP) machine. When a defect is detected by one of the onboard profilometry sensors, the RT-AFP machines reacts by automatically adjusting the process parameters (such as heating and compaction levels) in real-time. This capability is not available in existing commercial AFP machine. The RT-AFP machine therefore demonstrates the feasibility and benefits of active process control in AFP and lays the groundwork for future components to be manufactured right-first time.

The profilometry sensors installed on the testbench provide measurements of key material properties and process variables before, during, and after the material is deposited. This includes widths and thicknesses at both pre- and post-deposition stages, and the compaction and heating levels at the nip point. The sensor data is analysed in real-time by an advanced control system, as shown in Fig. 1. Data collected from these sensors are fed into an algorithm that controls the RT-AFP machine. If the measured thickness or width deviates beyond a pre-calculated tolerance, the algorithm will indicate a suspected defect and record its location. When this defect reaches the nip point, key AFP process variables (compaction, heating, and deposition rate) are automatically adjusted to compensate for the changes in the material's profile.

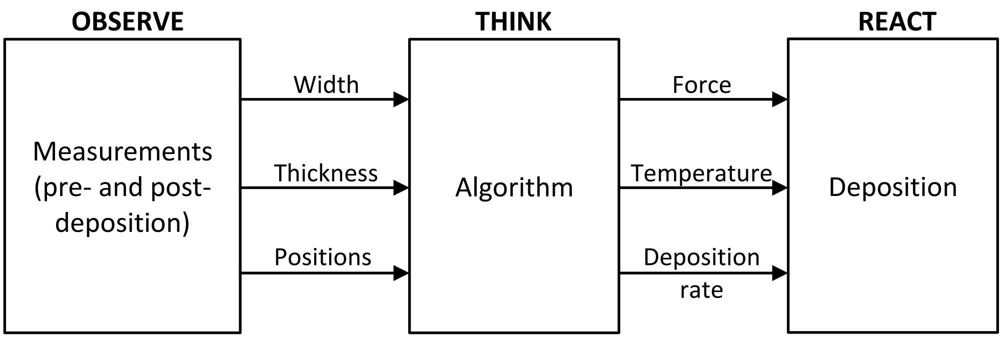

Figure 1. Schematic of the RT-AFP machine.

In the test, an 18-ply unidirectional laminate of length 400 mm was built using HexPly M91/34%/UD194/IM7-12K prepreg. The material has an averaged pre-cure dimensions of 12.7 mm in width and 0.31 mm in thickness. When no defect is present, the process parameters were kept constant at 300 mm/min deposition rate, 50 N compaction, and 30° C heating. Two wrinkle defects were artificially introduced by placing two PVC rods of diameter 3.2 mm on top of the second layer when the third layer is being deposited. The post-deposition scanner picks up these defects as increases in thicknesses and records their positions. Starting from the fourth ply, when the roller reaches the wrinkle location, compaction is increased to 150 N and the heat lamp is turned up to full power until the defect is clear of the roller, after which, the process parameters are brought back to 50 N and 30 °C again. The algorithm is programmed to respond only to the second defect while keeping the process parameters unchanged for the first wrinkle. This allows us to compare the effectiveness of in-situ process control for defect compensation.

Fig. 2 presents some key measurements recorded during the layup of the 18 plies. The two wrinkles are first detected as large rises in thickness when ply 3 is being laid down (noting that both wrinkles were created using identical 3.2 mm rods, and that the supposedly difference in thickness was due to small elastic deformations in their geometries). Starting from ply 4, the set points for compaction and temperature are automatically increased whenever the second wrinkle pass through the nip point (See Fig. 2). Control of the AFP machine was done automatically in real-time, although the choice to increase compaction to 150 N and heating to full power at the defect is arbitrary. Further developments can incorporate a database to the algorithm, enabling the latter to look up a suitable set of process parameters in response to different types and level of defects.

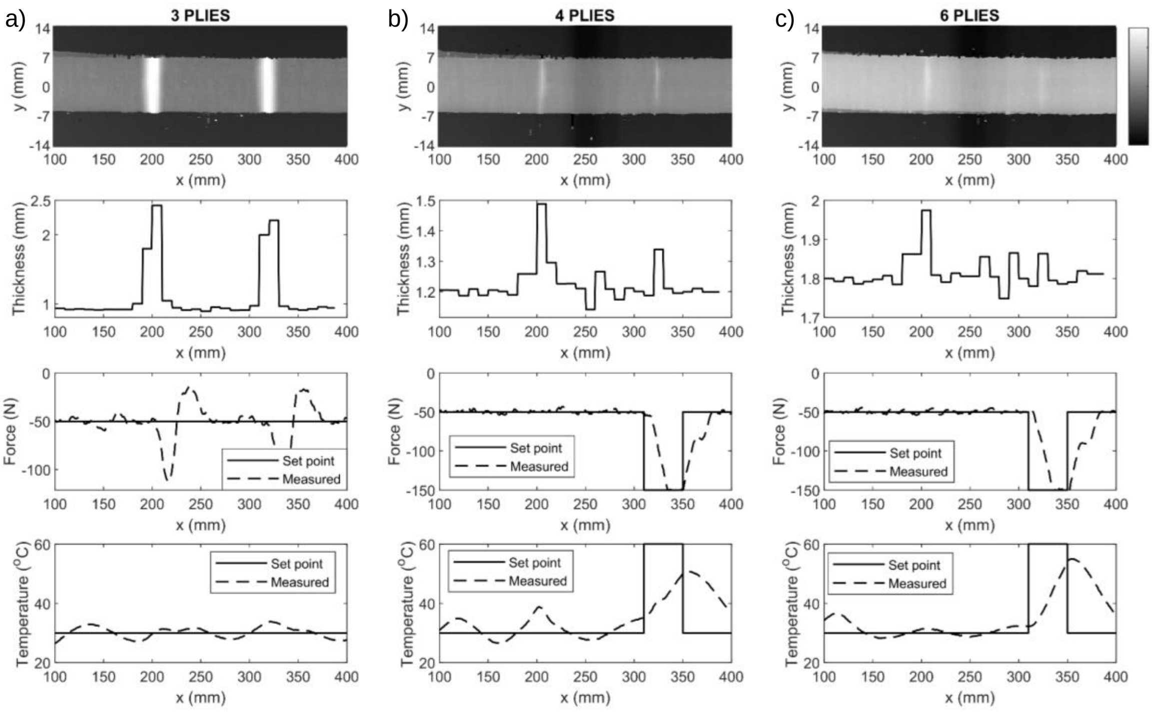

Figure 2. Post-deposition surface scan, thickness data, force data, and temperature data during layup of ply number 3 (a), 4 (b), and 6(c). Negative force indicate compaction. Note that thickness data is discretised and averaged into 10 mm strips.

It can be seen that by increasing compaction and heating at the second wrinkle, the defect can be flattened out and becomes less noticeable as more plies are added. On the other hand, the first wrinkle continues to propagate through subsequent layers.

Starting from ply 10, the second wrinkle became almost indistinguishable from its adjacent pristine sections. Automatic compaction and heating adjustments were therefore not triggered in plies 10-18. Instead, the set points used for these plies are the same as those shown in Fig. 2a.

The impact of automatic process control on the defects at the microstructure level is now examined. After deposition, the laminate was cured in an autoclave and then cut at 45^{o} in the middle of the two winkles. Fig. 3 compares their cross sections. In the first wrinkle (Fig. 3a), the lack of additional heat and compaction during deposition led to in-plane fibre waviness after curing. This is not an issue in the second wrinkle (Fig. 3b), where the changes in process parameters were sufficient to compensate for the defect and build a preform without excess fibre length that manifests as in-plane fibre waviness during autoclave consolidation and curing. Real-time process parameter adjustment can therefore control the material microstructure. Without such adjustments, the laminate may fail to achieve the required microstructure despite meeting dimensional tolerances. This can have severe effects on the strength of the final component.

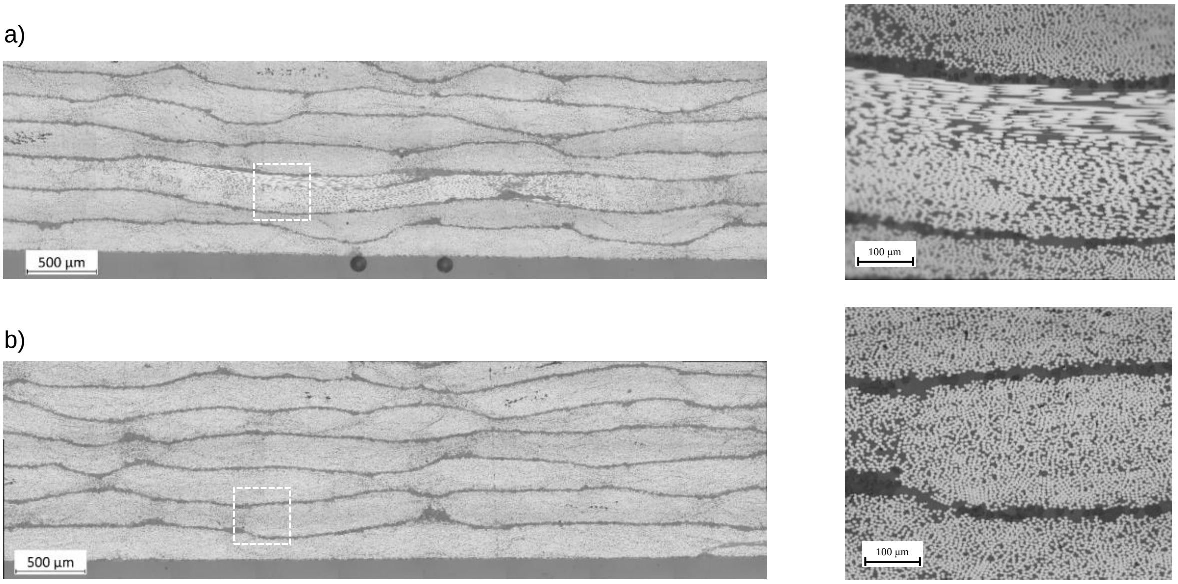

Figure 3. Microscopy images of the area of wrinkles 1 (uncorrected) (a) and 2 (corrected) (b). Note that all fibres in (b) are aligned in the expected orientation.

We have demonstrated the feasibility and benefits of the observe-think-react approach in AFP. It has been shown that by adjusting the process parameters in real-time, the material microstructure can be influenced and hence compensated for lay-up defects detected during deposition. Using the RT-AFP machine concept, further studies into fully-automated AFP, such as process parameter optimisation in response to different defect types and levels, are possible.

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References:

[1] Rudberg, T., Cemenska, J., Sherrard, E.: 'A Process for Delivering Extreme AFP Head Reliability', SAE International Journal of Advances and Current Practices in Mobility, 2019, 1, (2), pp. 333–342