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Modelling steering-induced defects in automated fibre placement

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The term Manufacturing 4.0 is becoming ever more common in the composite industry, referring to a concept in which machines are augmented with sensors in a system that intelligently controls and adapts production. One of the most common machines used for the manufacture of high value composites is automated fibre placement (AFP). In this study a finite element platform for the prediction of as-manufactured geometry of a preform deposited by AFP is developed. It is envisaged that, longer term, the proposed framework could be coupled with in-process sensing to allow on-line adaptation and optimisation of the process parameters to mitigate the formation of defects and increase productivity. As opposed to similar models, the proposed numerical scheme takes into account the viscoelastic nature of the contact behaviour of prepreg and also the in-plane shear behaviour that have been identified as two of the main drivers of out-of-plane defects generated during manufacture.

Automated Fibre Placement

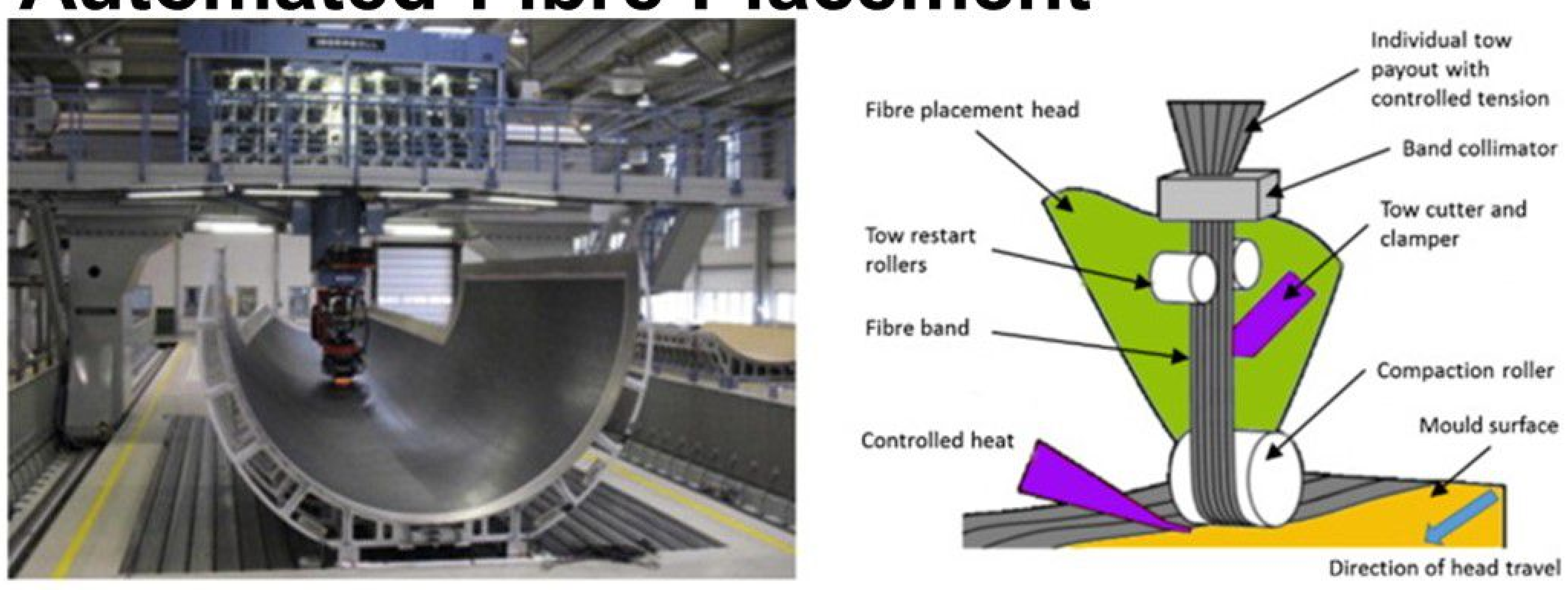

Fig.1. Schematic of the AFP layup process [1].

The process involves a robotic arm continuously depositing thin strips of prepreg onto a tool. The deposition process involves the simultaneous warming, lay-up and consolidation of prepreg consisting of multitude of process parameters. The majority of the process parameters for AFP are derived by expensive and time-consuming trial-and-error approaches to ensure part conformance, Fig. 2.

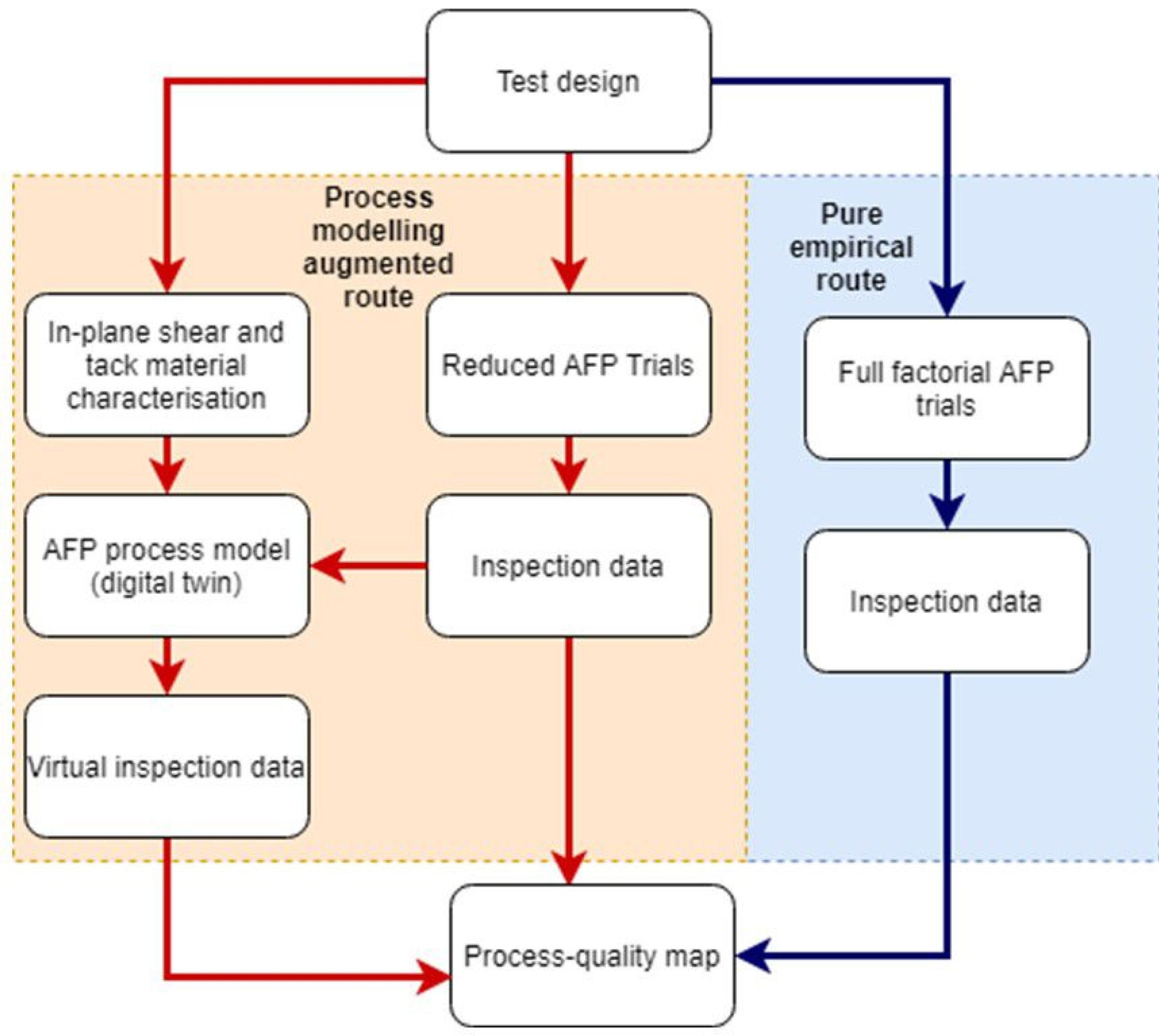

Fig. 2. Two routes to deriving process-quality map

Key research points

- Minimum steering radius as a function of process parameters is tabulated to avoid the extreme cases of these process induced variabilities, such as out-of-plane wrinkling and tow pull-up.
- The primary motivation of the present work is to reduce this empirical process development through a systematic use of a digital twin of the manufacturing process, Fig. 3.
- Generating a full factorial process-quality map empirically may require upwards of 200 AFP trials, but using existing material characterisation data [3] and process modelling, the augmented approach can reduce this to less than 20 trials.
- With the addition of a compaction model [2], this capability can be extended to full preform modelling.

Finite element AFP model

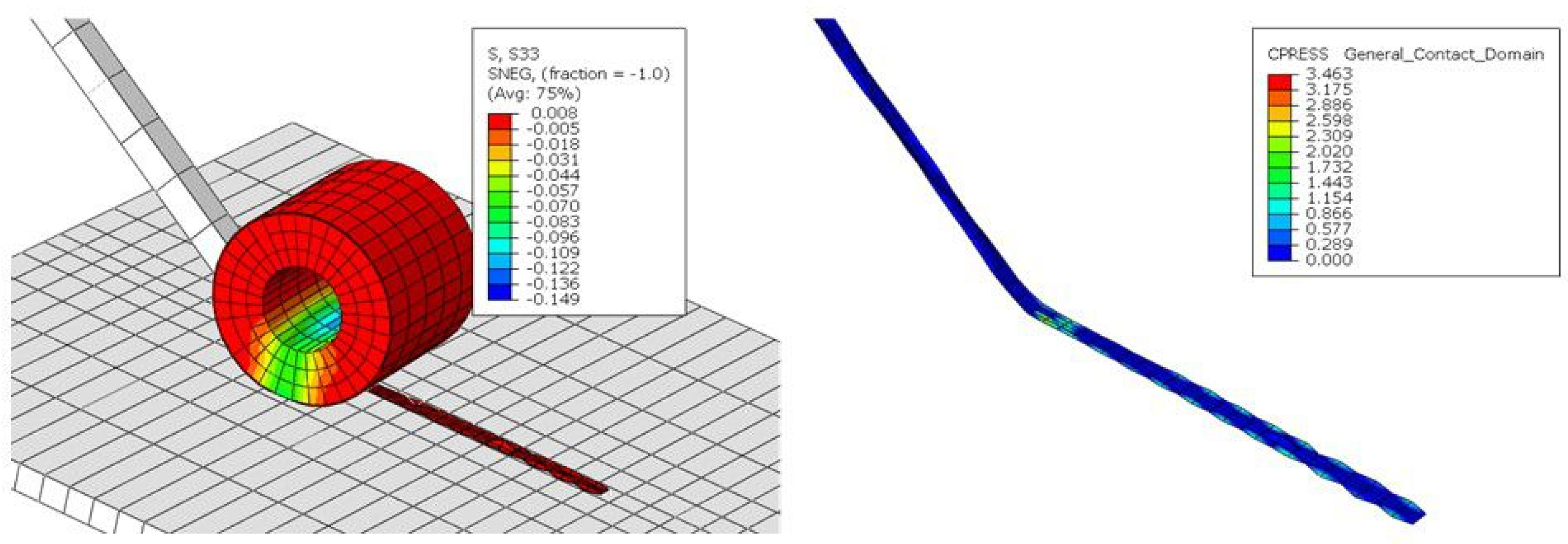

Fig. 3. Through thickness strain (left) and contact pressure in MPa (right) of a single 6mm wide IM7/8552 tow being deposited at 325mm/s and 35º C under 100N, with a radius of 4500mm.

[1] J. P. Belnoue, T. Mesogitis, O. J. Nixon-Pearson and J. Kratz “Understanding and predicting defect formation in automated fibre placement prepreg laminates”. *Composites Part A: Applied Science and Manufacturing*, vol. 102, pp 196-206, 2017.
[2] J. P. Belnoue, O. J. Nixon-Pearson, D. Ivanov and S. R. Hallett “A novel hyper-viscoelastic model for consolidation of toughened prepregs under processing conditions”. *Mechanics of Materials*, vol. 97, pp 118-134, 2016.
[3] Y. Wang, D. Ivanov, J. P. H. Belnoue, J. Kratz, B and S. R. Hallett “Modelling of the In-Plane Shear Behavior of Uncured Thermoset Prepreg”. *American Society for Composites*, USA, 2019.

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