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Computationally Efficient Finite Element Platform for Modelling Automated Fibre Placement

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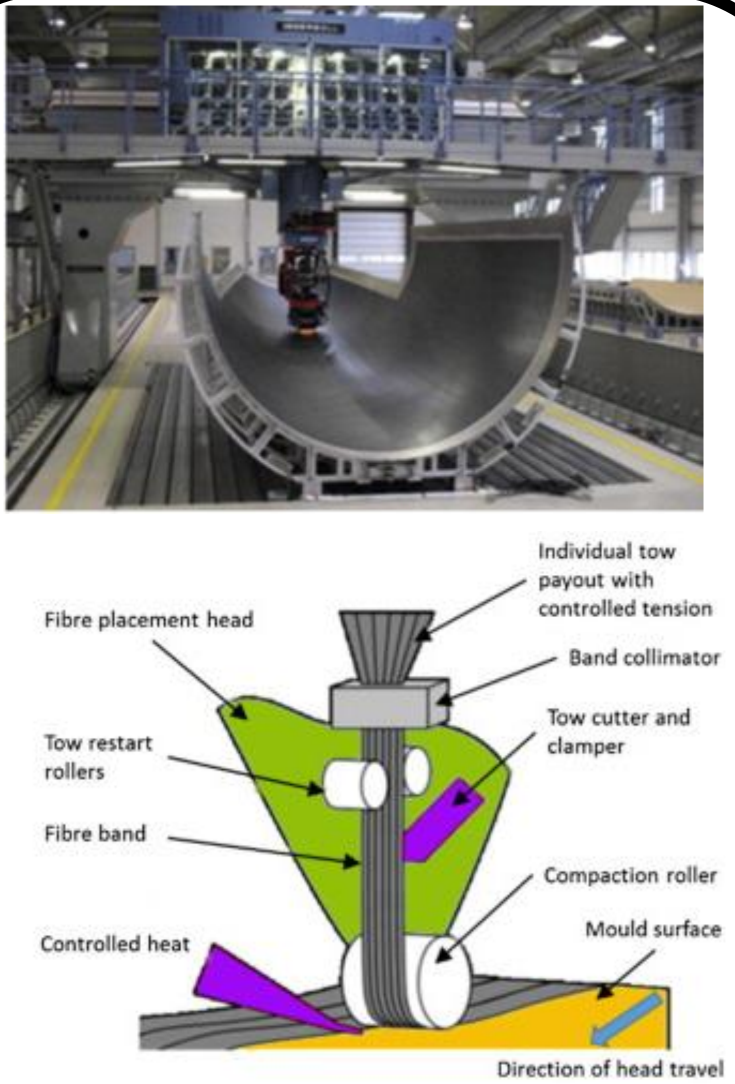
Contents

Background

- In an effort to increase composite production rate and reduce costs, the industry is turning towards automated manufacturing, like automated fibre placement.
- The method consists of automatically depositing strips of prepreg tows onto a mould using a computer-controlled robot.

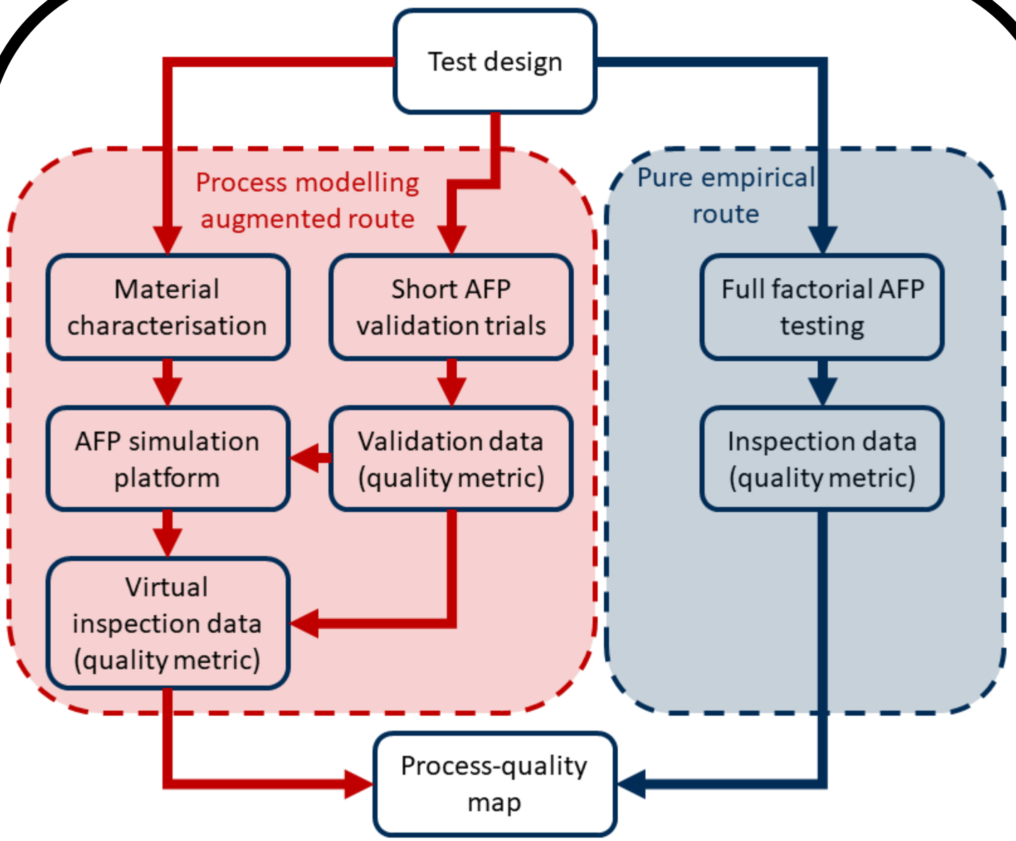


Schematic of the AFP layup process [1].

[1] Belnoue *et al.*, Understanding and predicting defect formation in automated fibre placement pre-preg laminates. *Composites Part A: Applied Science and Manufacturing*,(2017)

Background

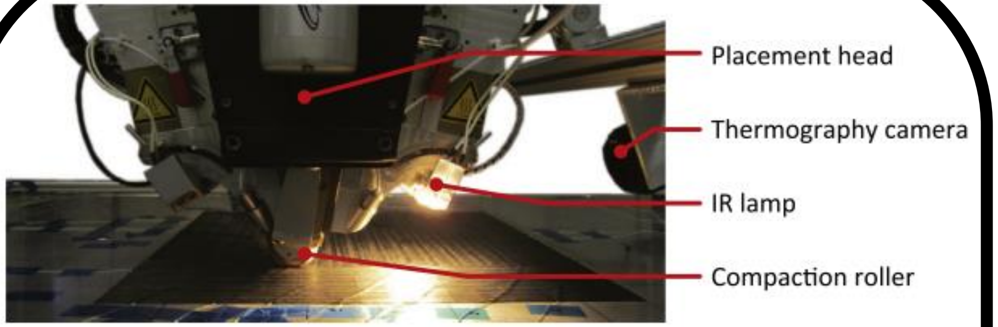
- Set-up of AFP is based on engineering judgement and time-consuming trials.
- Ability to predict as-manufactured geometry would allow for a clearer assessment between part quality, conformity and productivity.
- Linking Process-Material-Quality.



Development of process-material interaction map enhanced by process simulation.

Research Aims and Objectives

- The aim of the project was the development of a numerically efficient framework, which captures the process-quality interaction.
- To develop physics-based simulation platform to investigate material-process interaction during AFP and enable exploration of the entire processing window.



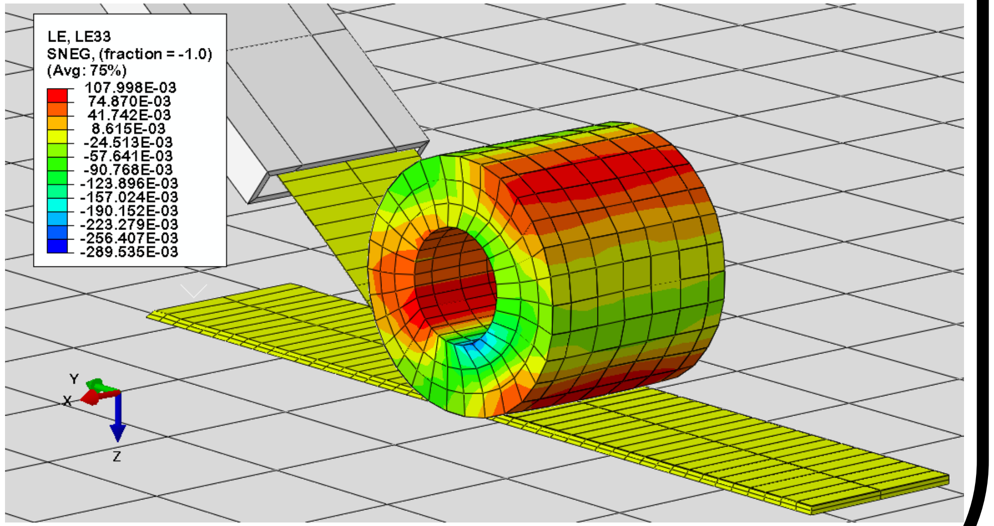
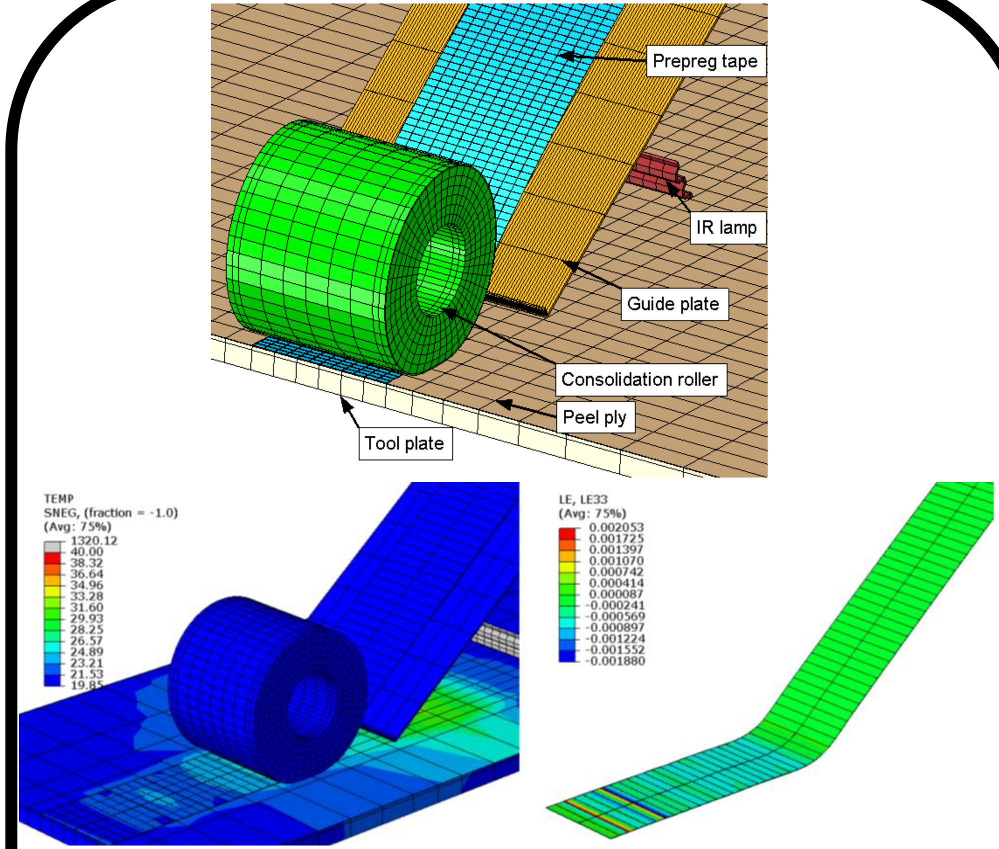


Image [2] and model of AFP head.

[2] Lichtinger, R., Hörmann, P., Stelzl, D., & Hinterhölzl, R. The effects of heat input on adjacent paths during Automated Fibre Placement. *Composites Part A: Applied Science and Manufacturing*, (2015).

State-of-the-Art

- Incudes a sequentially coupled FE model, adapted from TUM [2], with a experimentally characterised prepreg model [3].
- Impact of process parameters on preform geometry can be directly simulated.
- Computationally expensive, limited scalability with increasing ply count.



Sequentially coupled model of IM7 8552 tape under 125N roller force and 150W lamp power.

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[2] Lichtinger, R., Hörmann, P., Stelzl, D., & Hinterhölzl, R. The effects of heat input on adjacent paths during Automated Fibre Placement. *Composites Part A: Applied Science and Manufacturing*, (2015).
[3] Belnoue, J. P. H., Nixon-Pearson, O. J., Ivanov, D., & Hallett, S. R. A novel hyper-viscoelastic model for consolidation of toughened prepregs under processing conditions. *Mechanics of Materials,* (2016).

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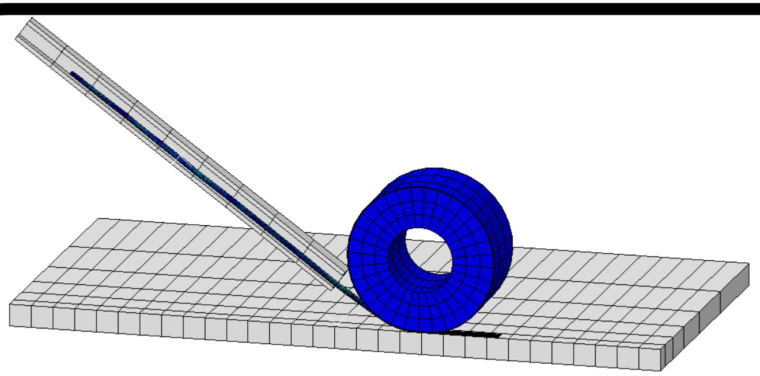
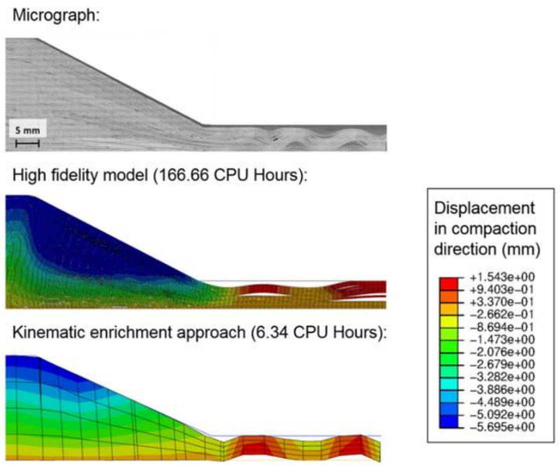
Computational Efficiency

- Constraining inconsequential deformations.
  - Rigid parts.
  - Containing undesired dynamic motion.
- Computationally efficient material model.
  - Homogenisation of substrate bulk.



Model cut-out with parts in white being rigid.

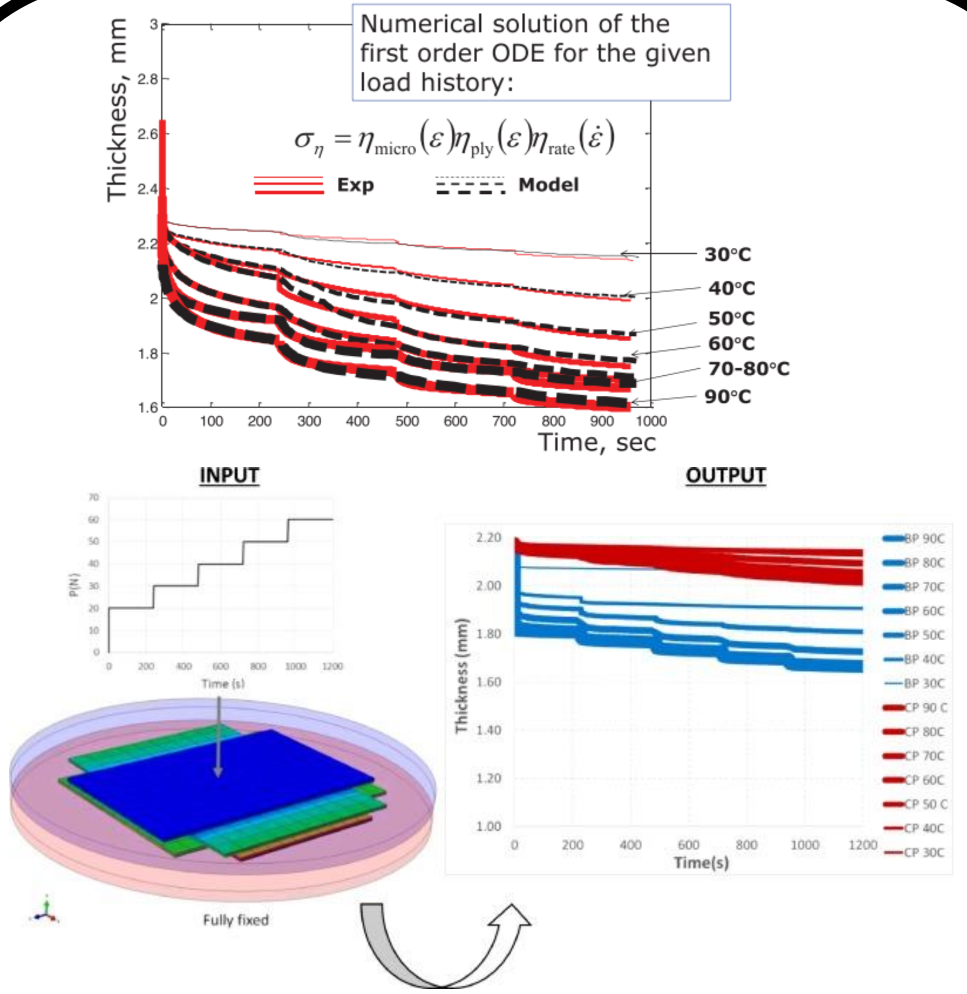


Comparison of the predictions for wrinkle formation in severely tapered laminate made by the ply-by-ply and the kinematic enrichment approaches [4].

[4] Belnoue, J. P. H. & Hallett, S. R. A rapid multi-scale design tool for the prediction of wrinkle defect formation in composite components. *Mater. Des. 187*, 108388 (2020).

Numerical Model

- The viscoelastic prepreg material model captures the compaction behaviour which leads to excess length generation.
- The material model was implemented as a UMAT subroutine for Abaqus/STANDARD.



Material characterisation workflow comprising of experimental program, parameter extraction and simulation [3].

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[3] Belnoue, J. P. H., Nixon-Pearson, O. J., Ivanov, D., & Hallett, S. R. A novel hyper-viscoelastic model for consolidation of toughened prepregs under processing conditions. *Mechanics of Materials,* (2016).

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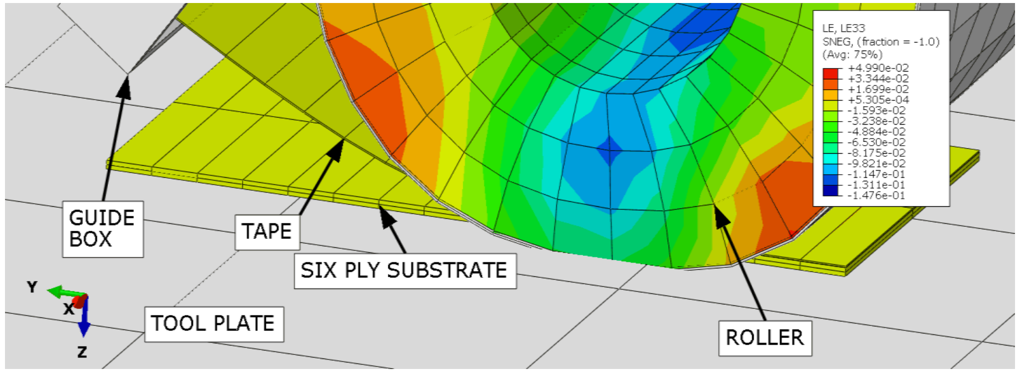
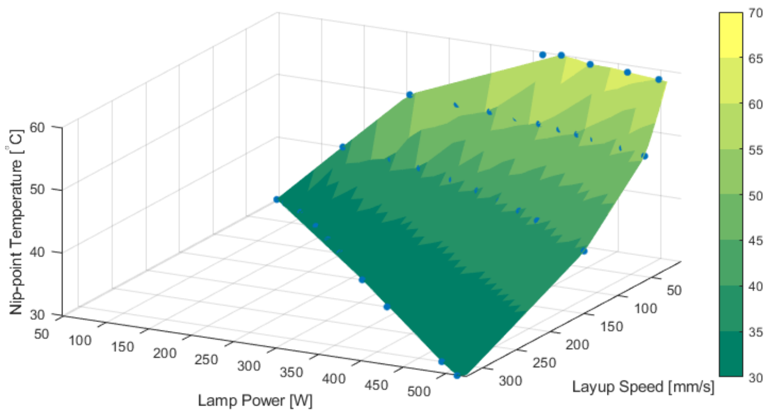
Numerical Model

- Current state-of-the-art AFP platform is built on ABAQUS, and includes:
    - Isothermal STANDARD model.
    - Linked with AFP power curves.
    - On-the-fly substrate bulk homogenisation.
    - Prepreg and roller material models characterised over a wide range of processing conditions[3].



Visual representation of isothermal model with homogenised substrate.

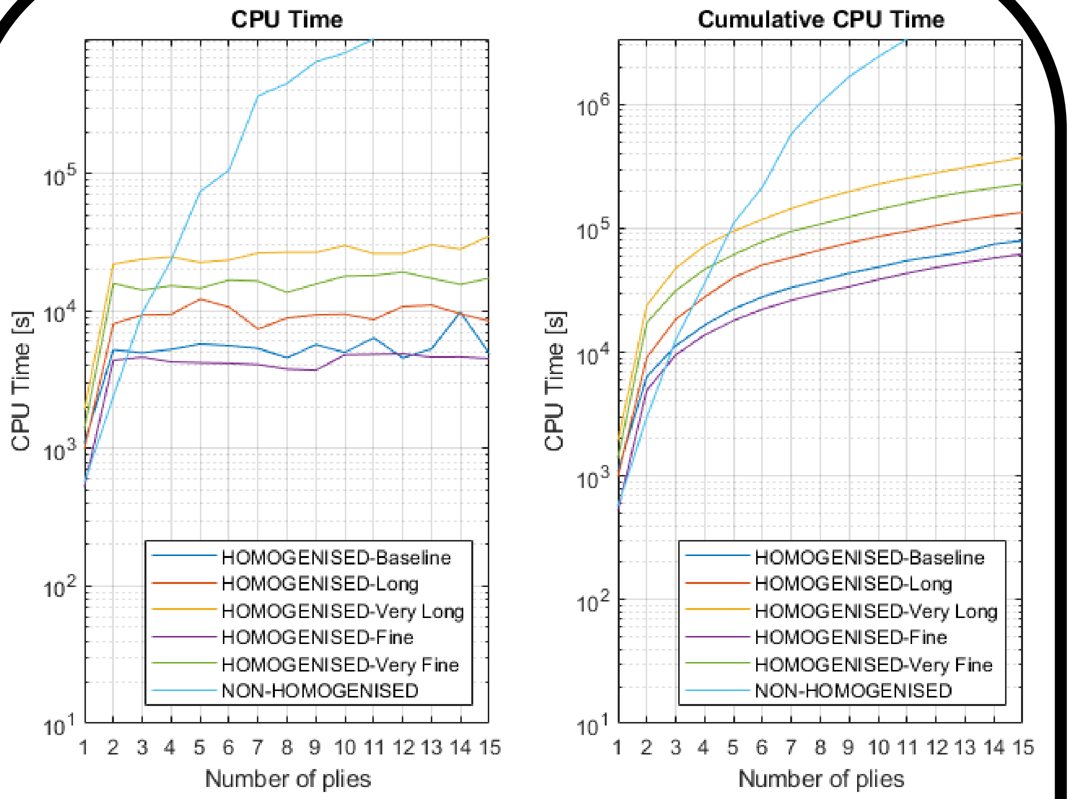


Empirical nip-point temperature map along with experimentally obtained fitting data points [5].

[5] Monnot, P. NCC Core Programme Year 9 (19/20) – Adaptive Automated Fibre Placement Manufacturing, 1–11 (2020).

Computational Efficiency

- Computational cost of a single 200mm tape layup:
  - Sequentially coupled (TUM): **24255s**.
  - Sequentially coupled, characterised material models (UoB): **44960s**.
  - Isothermal, fully deformable: **1922s**.
  - Isothermal, constrained deformations: **1074s.**

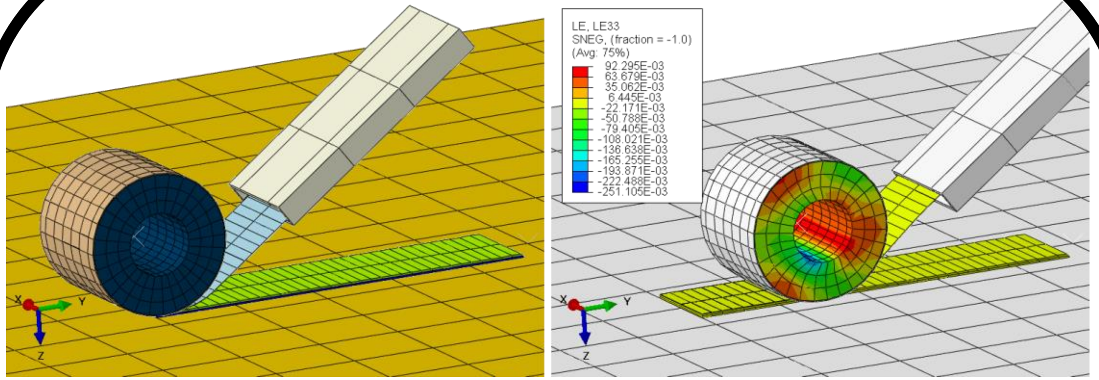


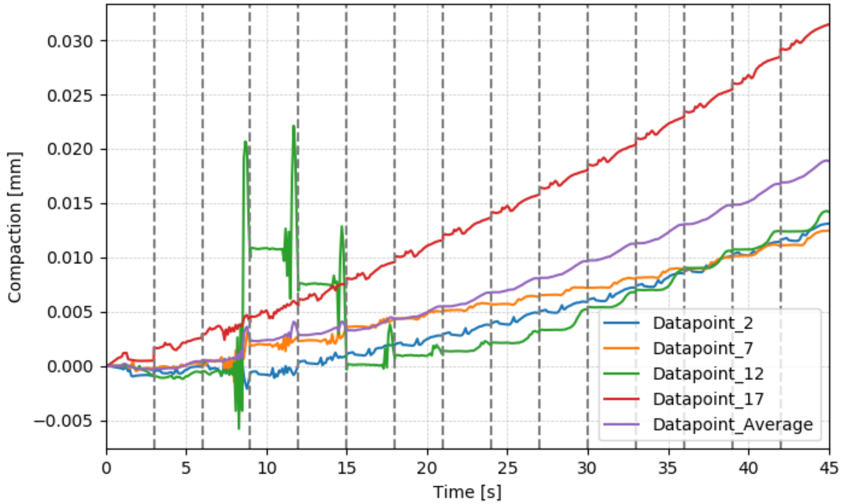
Comparison of run times for various AFP models, depositing 15 plies at 20mm/s under 425N of compaction force and 394W lamp power.

[2] Lichtinger, R., Hörmann, P., Stelzl, D., & Hinterhölzl, R. The effects of heat input on adjacent paths during Automated Fibre Placement. *Composites Part A: Applied Science and Manufacturing*, (2015).

Numerical Study

- Seven layup cases were investigated with the following range of processing parameters:
  - Lamp power: 131 – 394W
  - Compaction force: 120 – 425N
  - Layup speed: 20 – 60mm/s
- Fifteen 0º IM7/8552 plies consisting of eight 6.35mm (¼in) tows were laid up at the NCC [5].





Preform compaction evolution of 15 ply deposition at 50mm/s under 425N of compaction force and 394W lamp power.

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[5] Monnot, P. NCC Core Programme Year 9 (19/20) – Adaptive Automated Fibre Placement Manufacturing, 1–11 (2020).

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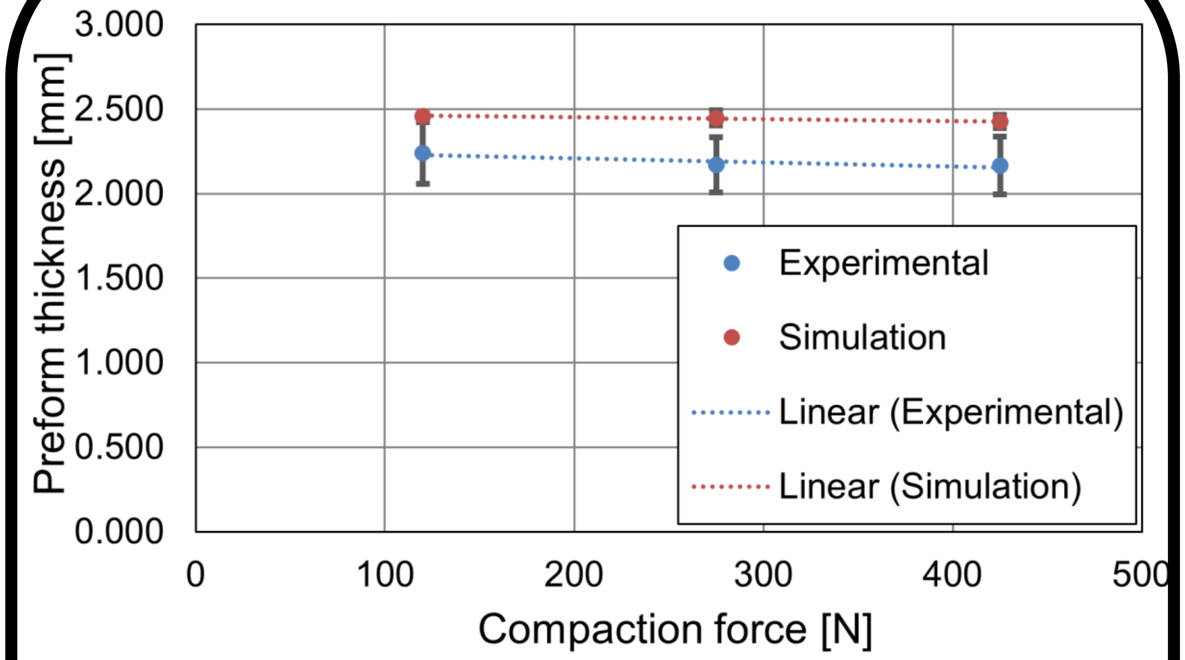
Numerical Study

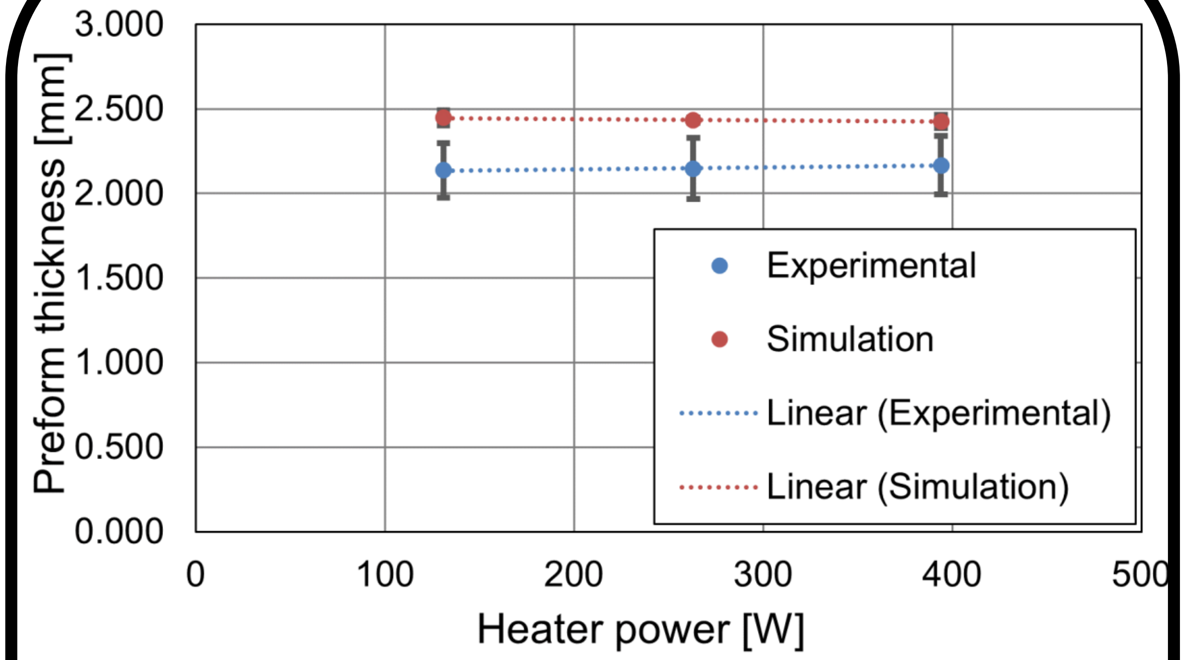
- Under the specified process range and preform thickness, slight variation in compaction is observed.
- Preform compaction increases with:
    - Increasing compaction force.



Evolution of average preform thickness with compaction force.

Numerical Study

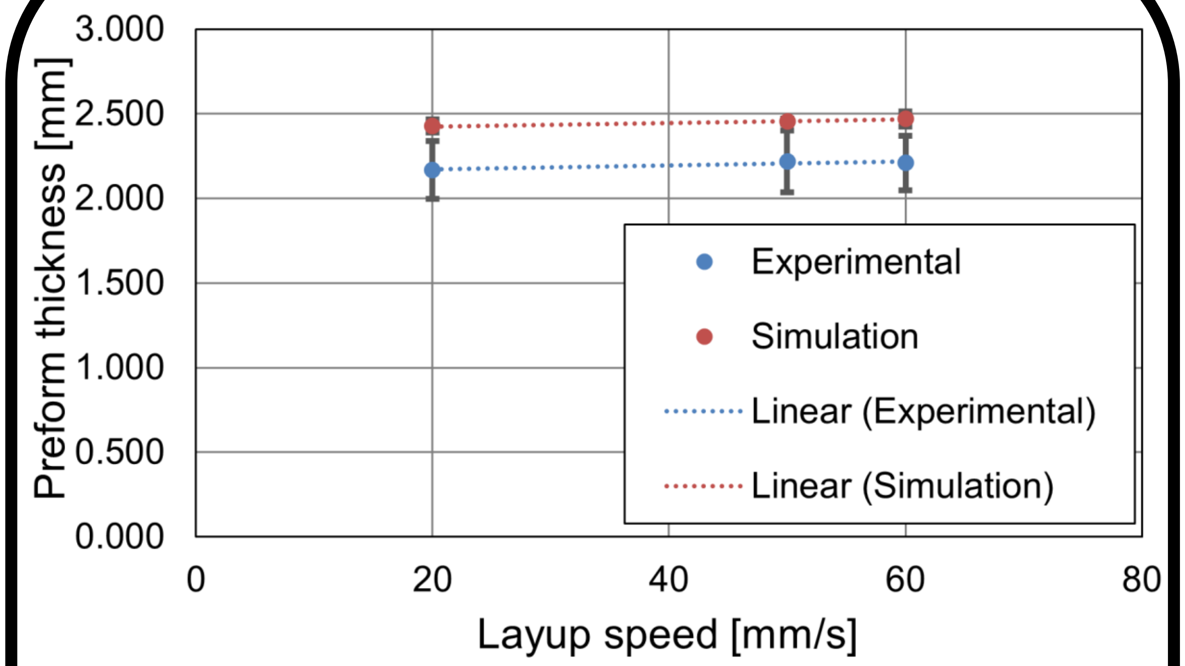
- Under the specified process range and preform thickness, slight variation in compaction is observed.
- Preform compaction increases with:
    - Increasing compaction force.
    - Increasing lamp power.



Evolution of average preform thickness with heater power.

Numerical Study

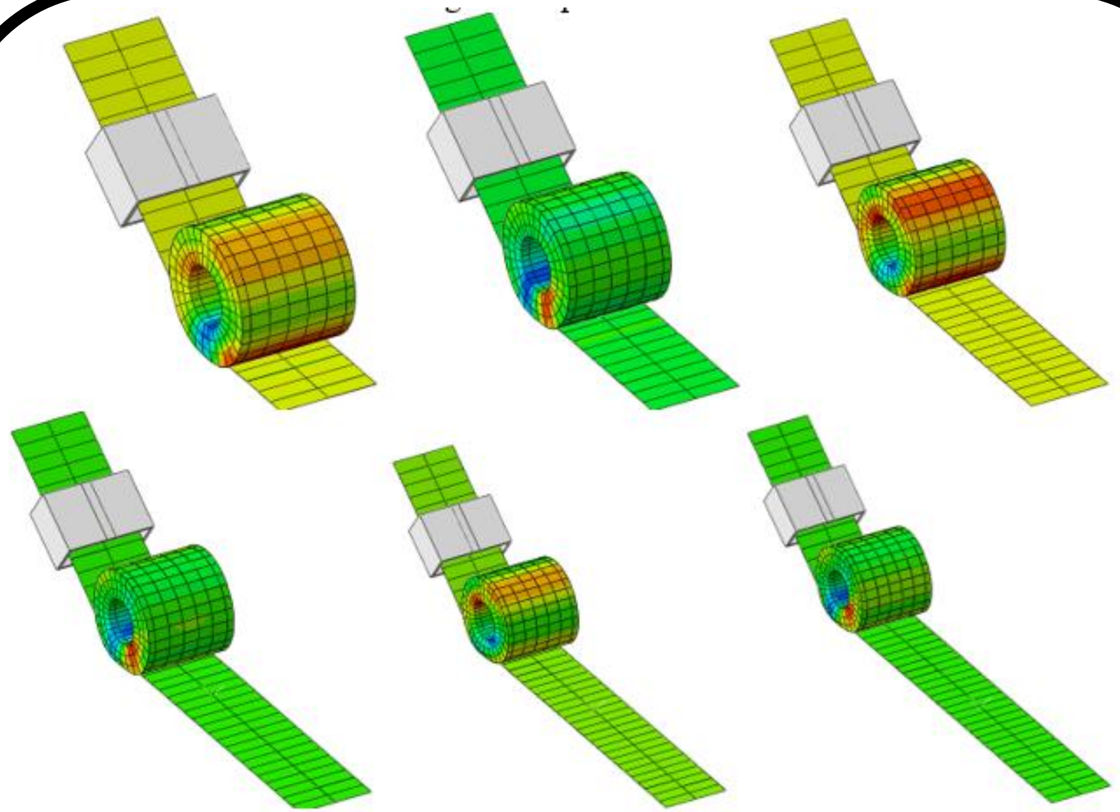
- Under the specified process range and preform thickness, slight variation in compaction is observed.
- Preform compaction increases with:
    - Increasing compaction force.
    - Increasing lamp power.
    - Reducing layup speed.



Evolution of average preform thickness with layup speed.

Ongoing Activities

- Further improvements, which include:
  - On-the-fly length generation.
  - Through-thickness preform temperature variation.
- Introduction of complex layup paths and tool surfaces.
- Further tuning of platform to improve accuracy.

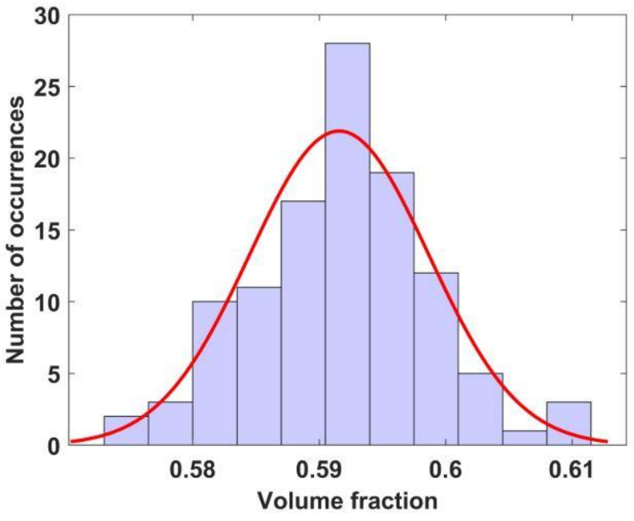


On-the-fly mesh generation of 50mm section in each step.

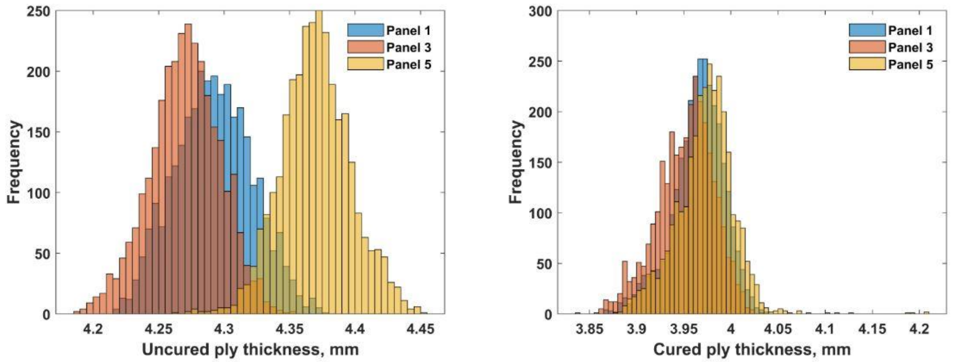
[4] Belnoue, J. P. H. and Hallett, S. R. 2020. "A rapid multi-scale design tool for the prediction of wrinkle defect formation in composite components." Materials and Design, 187(2020) 108388.

Conclusion

- Capable of capturing the influence of wide range of processing conditions on conformance.
- The process map can give guidance to current AFP projects or be used a first approximation.
- Future work includes validation, inclusion of material variability and smart process map exploration.



Distribution of the fibre volume fraction [6].



Measured uncured ply thickness (a) and the resulting ply thickness (b) of the 4mm laminate subject to the predefined autoclave cycle [6].

[6] Gongadze, E., Belnoue, J. P., & Hallett, S. R. (Accepted/In press). Thickness control of autoclave-moulded composite laminates. *Journal of Manufacturing Science and Engineering*.

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