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Defect Prediction and Mitigation in Woven Thermoplastic Composite Laminates

George. E. Street[1], Dr Michael. S. Johnson[1], Dr Hengan Ou[2]

[1]Composites Research Group, Faculty of Engineering, The University of Nottingham, Nottingham, UK

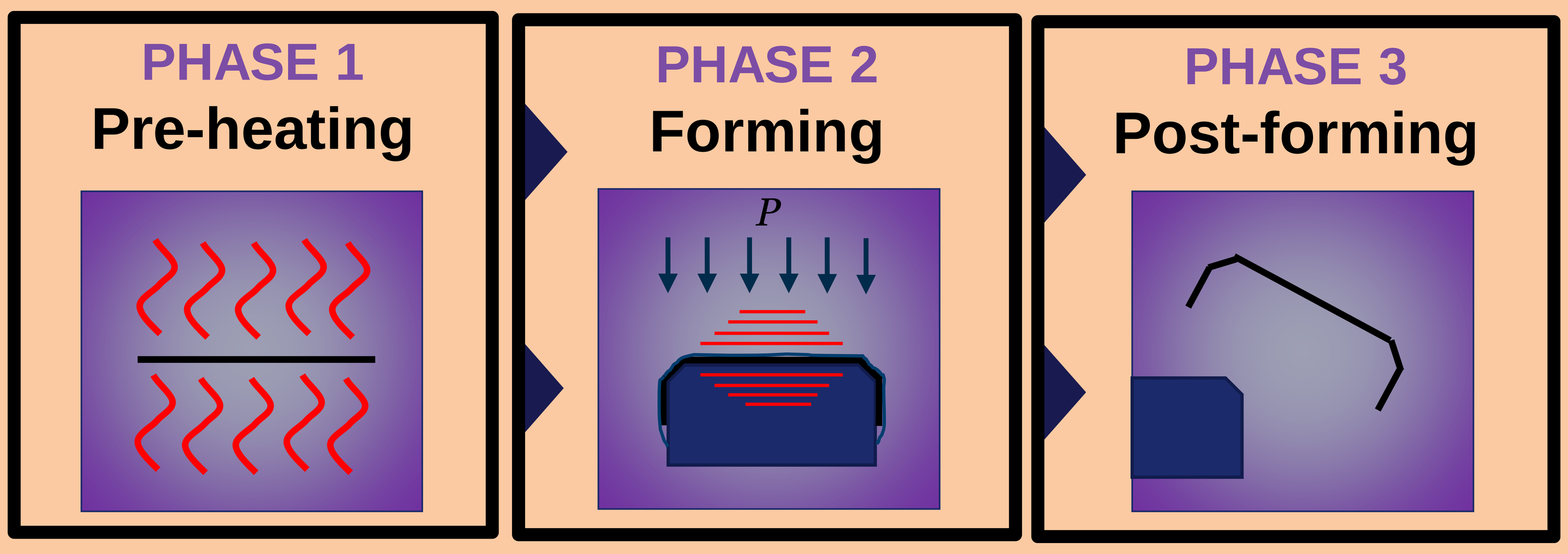
[2]Advanced Manufacturing Research Group, Faculty of Engineering, The University of Nottingham, Nottingham, UK

1. Introduction

Woven fibre reinforced thermoplastic (FRTP) composites are a promising alternative to conventional thermoset composites. This is due to the low manufacturing times that can be achieved, coupled with the enhanced joinability and recyclability of the thermoplastic reinforcing material [1].

Current FRTP manufacturing is constrained, however, due to the heating requirement of the thermoplastic matrix and the forming behaviour of the viscoelastic material. These intricacies exacerbate the occurrence of defects within formed components.

Typical FRTP forming process [2]

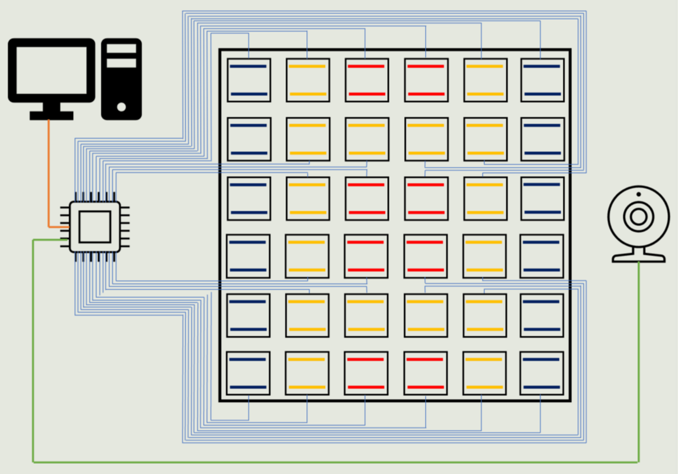


3. Defect Reduction

With accurate simulation it is possible to optimise the forming process to reduce defects that may occur within an FRTP laminate. These defects can be categorised in two subsections, namely; **fabric defects** and **shrinkage defects** [4].

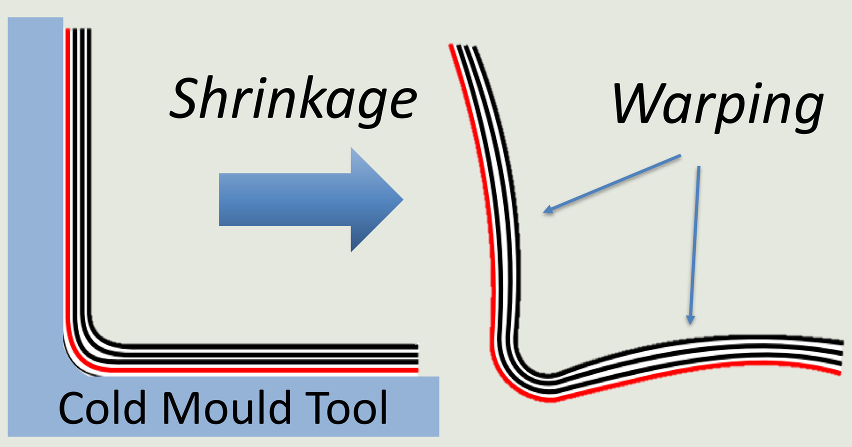
Fabric Defects

A pixelated heater array with closed-loop pyrometer feedback has been proposed for blank heating to optimise the temperature at different locations along the laminate profile for optimal forming.



Shrinkage Defects

Tailoring of residual stresses (advanced cooling) within the laminate facilitates a reduction in warping and buckling behaviour.



[1] Akkerman R, Haanappel SP. 6 - Thermoplastic composites manufacturing by thermoforming. In: Boisse P, editor. Advances in Composites Manufacturing and Process Design: Woodhead Publishing; 2015. p. 111-29.

[2] Florian J. Practical Thermoforming: Principles and Applications. Boca Raton: CRC Press, 1987.

[3] Kouwonou K, Pham X-T, Lebrun G. Modelling and characterization of thermoplastic composites peek/carbon. 2013.

[4] Wolthuizen D, Schuurman J, Akkerman R. Forming Limits of Thermoplastic Composites. Key Engineering Materials. 2014;611-612:407-14.

2. Defect Prediction

Enhanced FRTP defect prediction necessitates accurate numerical simulation in a finite element (FE) package. This work therefore proposes the implementation of a **thermomechanical simulation**, including both material temperature and rate effects during the forming process.

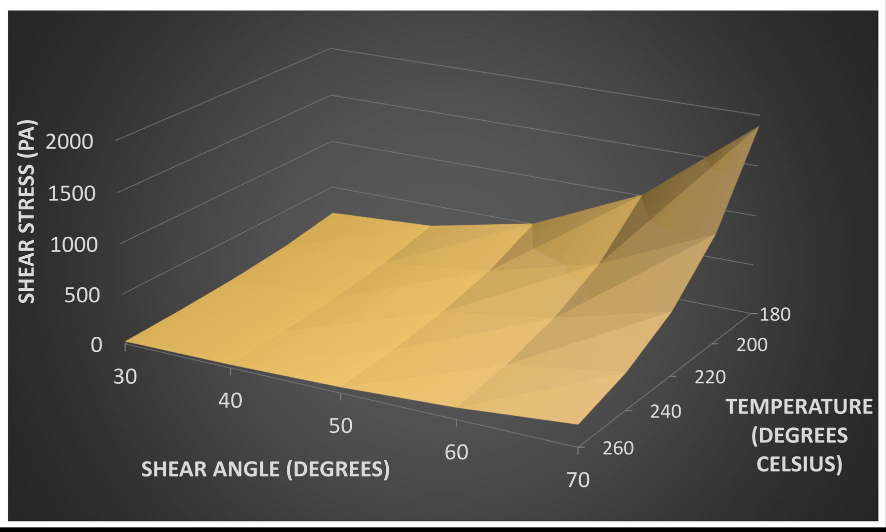
A FRTP thermomechanical model relies heavily on the associated material characterisation exercises [3]:

Forming Characterisation

Carbon Fibre/PA6 non-isothermal intra-ply shear characterisation:

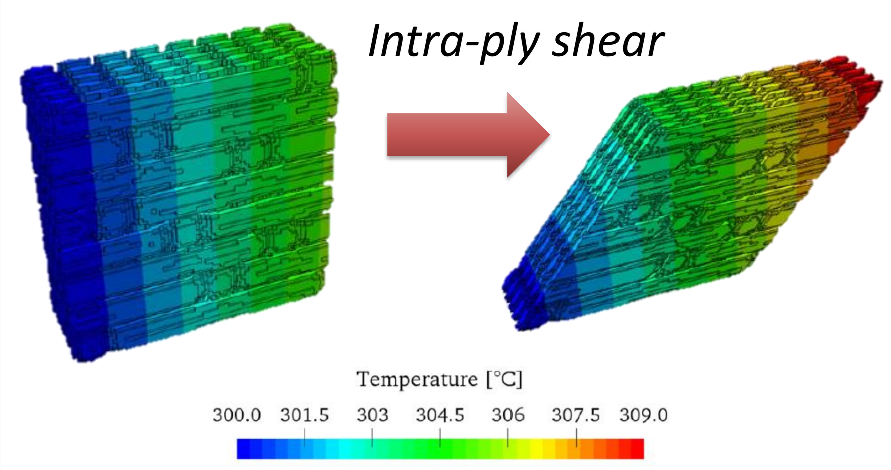
Shear force relation

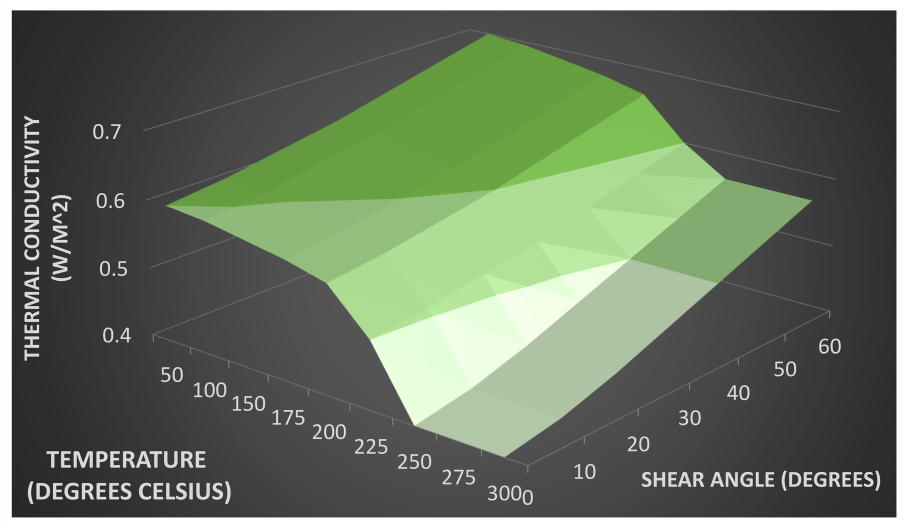
$$\tau_{12} = \left(1 + \frac{\dot{\gamma}}{0.0979}\right)^{1/1.978} \cdot \left(\alpha_1\gamma + \alpha_2\gamma^2 + \alpha_3\gamma^3\right)$$



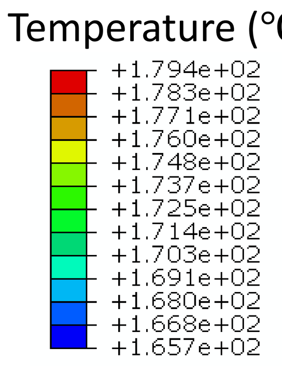
Thermal Characterisation

Mesoscale conductivity analysis (including shear dependence):

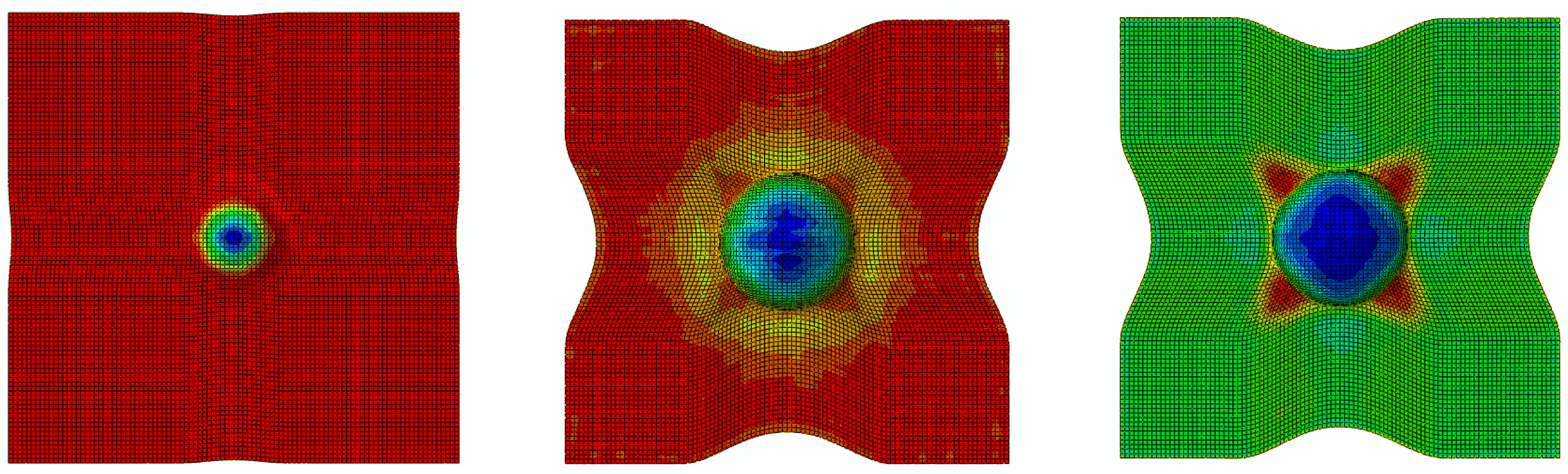




Thermomechanical Simulation



Thermomechanical simulation illustrating the back face cooling of an FRTP laminate during forming on a 25℃ hemisphere (initial temperature = 190℃)



Time = 1s *Time = 3s* *Time = 5s*

Forming Process

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