THROUGH THICKNESS RESIN FLOW AND HEAT TRANSFER MODELLING OF PARTIALLY IMPREGNATED COMPOSITE MATERIALS FOR THICK-SECTION PARTS

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Introduction

Partially impregnated precursor materials, or 'semi-pregs', have become an attractive alternative to typical precursor materials used in out-of-autoclave (OOA) processing, such as fully impregnated prepregs. One of the main reasons for this is that the fibres that have not been impregnated act as a pathway for air and moisture evacuation during vacuum consolidation, thus reducing the likelihood of void formation due to entrapped gases [1]. In this presentation the material used is a uni-directional stitched glass-fibre fabric with a single component epoxy powder calendared onto one side. This epoxy powder contains a latent curing agent which signifies a much greater out-life and produces a lower exotherm when processed at high temperatures. These combined advantages have made this material attractive for renewable energy applications such as wind and tidal turbines due to the need for cost effective blades without compromising quality. When combined with appropriate tooling, this material has already been used to manufacture 13m wind turbine blades [2]. By modelling both through-thickness resin flow and heat transfer for a thick laminate (40 mm), it should be possible to advance the development of this material and process larger, thicker wind and tidal turbine blades.

Model Description

In the case of partially impregnated materials, micro-scale flow within the fibre tows is dominant in dictating the impregnation time and can be modelled in a number of ways [3, 4]. In the present work, the aim is to model through-thickness flow for non-isothermal conditions, as illustrated in Figure 1. To achieve this, a finite difference code was developed in MATLAB using Darcy's Law for dual-scale flow coupled with heat transfer. The resin flow model assumes that the fibre layers remain rigid under compaction of atmospheric pressure and that all air has been evacuated. The resin layers are finite so that thickness change can be tracked with respect to time.

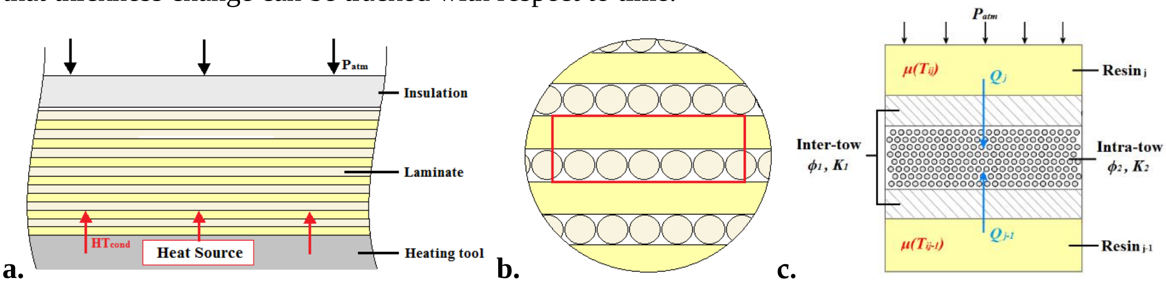

Figure 1: *Physical representation of the model; (a) a thick laminate (40 mm) has heat applied from the bottom surface and is insulated on the top surface, (b) the laminate is made up of 'semi-preg' plies, which can be viewed as unit cells, (c) the unit cell in the model can account for flow from both its own resin layer and the resin layer below.*

In order to determine the viscosity change with temperature, a heat transfer model was included in the code. For a given number of 'semi-preg' plies in series, a heat transfer model can be developed which numerically solves the 1D heat equation, using a forward-time central-space (FTCS) scheme [5]. In the model presented, 40 plies of material are included in order to simulate the processing of a thick section. The boundary condition at the surface of the tool assumes that the surface temperature can respond instantaneously to slow temperature ramp rates (e.g. 1.5°C/min), and the boundary condition on the top surface of the laminate assumes it is insulated. Modelling of the curing process is not within the scope of this work currently.

Results

Initial results for the model show the importance of heat transfer for resin flow in thick laminates. In a typical processing cycle, the material would be held at a high temperature (e.g. 120°C) to allow sufficient time for complete impregnation before the initiation of cure. Assuming the same temperature-dependent thermal conductivity as Murtagh et al [5] for powder resin and glass fibres (approx. 0.12 – 0.19 W/m.K), Figure 2 shows that the material effectively acts as an insulator and restricts heat transfer through the thickness. The thickness change is rapid initially as the resin fills the inter-tow region (permeability cerca 10^{-10} m^2), but slows down significantly as it begins to impregnate the tows (permeability cerca 10^{-14} m^2). The model results show some agreement with thermocouple data for an 80 mm thick laminate processed under vacuum in an oven i.e. the heat source is from both top and bottom of the laminate.

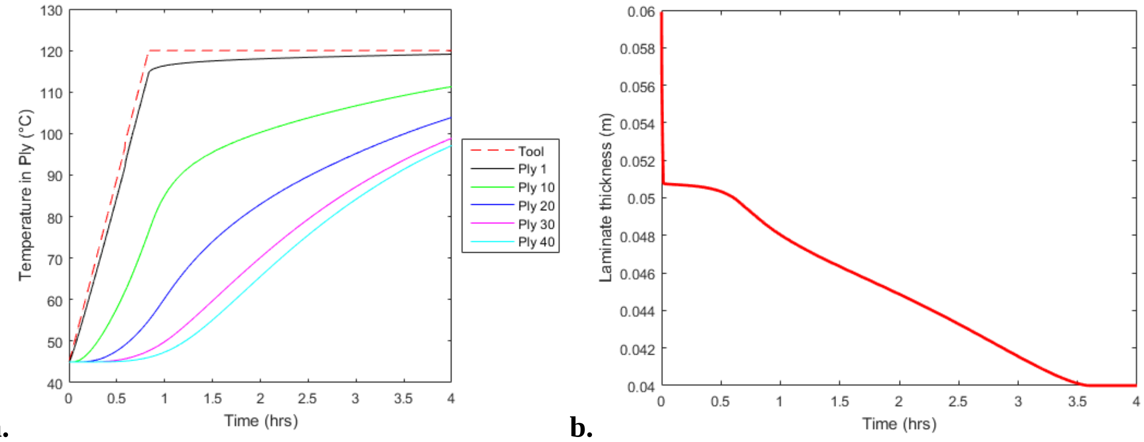

Figure 2: *Results of the resin flow and heat transfer model; (a) significant thermal lag in the plies further from the tool surface, (b) laminate thickness reduction slows as the resin begins impregnating the tows. The heating rate was 1.5 C/min until the tool surface temperature reached 120°C and then it was held constant*

Conclusion

The work presented is an initial approach to couple dual scale resin flow and heat transfer modelling for processing thick-section parts such as the root section of a wind or tidal turbine blade using a relatively inexpensive technology. The technology combines a cost-effective precursor material with novel integrally-heated ceramic tooling, but greater understanding is required in order to maintain part quality. The model is currently in development and experimental testing will be important for validation and improvement. Introduction of chemo-rheological data should allow addition of the heat generation to the model to include curing phenomena which will help heat up the intermediate plies more quickly and achieve the consolidated thickness much faster than currently predicted.

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