SIMULATION OF RESIN FILM INFUSION PROCESS USING FINITE ELEMENT/ NODAL CONTROL VOLUME APPROACH

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ABSTRACT

A numerical scheme, which is interfaced with a general-purpose finite element package for the simulation of resin film infusion process, is presented. The movement of the resin within the film and the impregnation of the fabric preform are modelled simultaneously as a fixed boundary problem. Application of the scheme is demonstrated by simulating the fabrication of a generic L-section.

1.INTRODUCTION

In resin film infusion process (RFIP) of composites manufacturing, a partially cured (B-stage) resin film is placed into a mould together with a fibrous media. The lay-up is subsequently subjected to a pre-defined cure cycle. As the temperature cycle progresses, viscosity of the resin film decreases. The low viscosity resin then permeates and impregnates the preform under the applied vacuum and/or pressure conditions. As a result, thickness of the resin film continuously reduces until the resin film is completely exhausted or the preform is fully saturated. Numerical simulation of this process is complex because the boundary of the film moves with the reduction in the film thickness.

To avoid the complexity in modelling such a moving boundary problem, some researchers attempted indirect approaches. Ahn et al. [1] developed a one-dimensional analytical model based on Darcy's law. This model assumes a linear pressure gradient across the laminate thickness and can be applied only to a simple geometry and the process conditions. MacRae et al.

[2] developed a numerical procedure for two-dimensional simulation of RFIP based on the finite element/ nodal control volume (FE/NCV) approach. They simulated the process as a non-isothermal resin transfer moulding (RTM) by modelling the resin film as a series of resin injection ports. The presence of the resin film was ignored in their analysis. The effect of the film on heat and mass transfer in the fabrication assembly and the changes in the film geometry cannot be accounted for using their approach.

In this paper, a three-zone model is presented using which, in addition to the fabric, the resin film can be modelled as an individual constituent in the lay-up. Movement of the resin within the film and impregnation of the of the numerical model and the simulation procedure for RFIP are discussed in porous fabric preform can be modelled simultaneously as a fixed boundary problem. The development the paper. Finally, the application of the developed procedure is demonstrated by simulating the fabrication of an RFIP L-section.
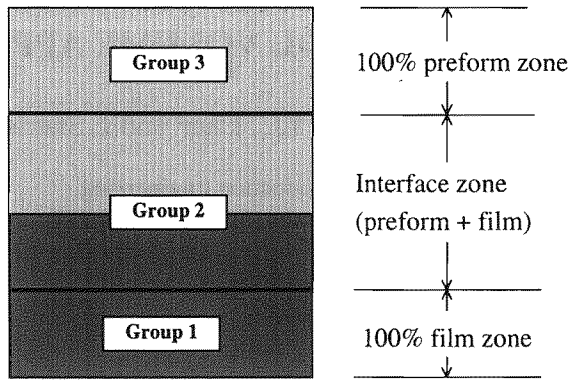
Fig. 1 : Schematic of a three-zone model for *RFIP* simulation.

2.A THREE-ZONE MODEL

Unlike *RTM*, the composite lay-up in *RFIP* consists of two distinct materials namely, the resin film and the fibre preform. There also exists an interface between the film and the preform. As per the definition of a control volume, such an arrangement leads to the formation of three different groups of control volumes as shown in Fig. 1. Using these three groups, the characteristics of each zone can be defined and evaluated independently and, the complete resin movement can be tracked very easily.

3.FILL AND UNFILL FACTORS

In order to track the movement of resin within the preform, the concept of *FILL* factors, commonly used in *RTM* simulation [2,3], was applied in the present formulation.

Unlike *RTM*, in *RFIP* the tooling on one side of the lay-up is allowed to move. As the curing cycle progresses, viscosity of the resin decreases and the resin starts moving towards the preform under the applied vacuum and/or pressure. The movable section of the tooling closes the gap created by this resin movement and the displacement of the tooling can be estimated by quantifying the loss of resin from the film. In the present model, a factor called *UNFILL* factor, was introduced for this purpose. It is defined as the ratio of the amount of resin that has moved out of a control volume to the total geometric volume of the control volume. This factor is applicable only to the film and interface control volumes. It varies from 0 to 1, the two extremes indicating the resin-full and no-resin conditions respectively. Thus, the term *(1.0-UNFILL)* always represents the resin volume fraction of a control volume.

4.INITIAL AND ALLOWABLE RESIN VOLUME CONTENTS

Two new factors, *RFIL* and *RCON*, were also introduced to define the initial and allowable resin volume contents of a control volume respectively. For the film control volumes, *RFIL* is equal to *RCON*, and, the both are equal to *1.0*. *RFIL* for the preform control volumes is equal to 0.0 whereas *RCON* is equal to the porosity of the preform. For the interface control volumes these factors are estimated as:

RCON =(volume pccupied by preform x porosity of preform)/*CVOL*   (1)

RFIL =(volume occupied by resin film)/*CVOL* (2)

where,

CVOL is the geometric volume of a control volume.

These two factors help in calculating the maximum amount of resin likely to be flown out or can be accommodated within any control volume from any of the three groups of control volumes at any stage of the preform impregnation process.

If *FILOUTM* defines the amount of resin available in a control volume, which can be supplied to any other control volume and, the *PREINM* is the amount of resin required to completely fill a control volume, then:

$$FILOUTM = (1.0 - UNFILL) \times RFIL \times CVOL \quad (3)$$

$$PREINM = (1.0 - FILL) \times (RCON - RFIL) \times CVOL \quad (4)$$

Thus, the filling and unfilling conditions can be simultaneously monitored using the above factors for all the three types of control volumes.

5.SOLUTION SEQUENCE

In the present analysis, the effects of the resin film and its reducing volume content on the heat and mass transfer were taken into account by scaling up the thermal conductivity and by scaling down the density of the film control volumes with the increase in their *UNFILL* factors. The geometry of the control volumes, and as a result, of all the finite elements, was kept constant throughout the analysis. Thus, only one FE mesh was used in entire simulation.

A *FE/NCV* procedure to simulate non-isothermal *RTM* process is discussed in detail by the authors in Ref. [3]. It was based on the combined use of general-purpose *FE* package *LUSAS* and the user-written computer programs. *RFIP* is essentially a non-isothermal process. Therefore, the three-zone model and various factors discussed in the previous three sections were integrated with the procedure described in Ref. [3] to perform *RFIP* simulation. The developed procedure was validated by conducting experimental and numerical studies on *RFIP* for carbon composite flat laminates; the results are given in Ref. [4]. An example on an L-section is presented below to demonstrate the application of the procedure.

6.APPLICATION OF THE MODEL

For the chosen L-section, a 12 ply thick, [0/90], plain-weave, T300 carbon fabric preform, with its permeability equal to 8.82E-11 m^2 in in-plane directions and 1.88E-13 m^2 in through-thickness direction, was used as reinforcement. A Hercules

3501-6 resin-film was chosen for matrix. Although the actual self-contained fabrication assembly for the L-section was three-dimensional, it had constant cross-section in lengthwise direction. Therefore, two-dimensional simulation was sufficient. A *FE* model of the two-dimensional section of the fabrication assembly was created using 441 four-noded, quadrilateral, field elements from *LUSAS*. The *FE* model with a few other details is shown in Fig. 2. The employed cure cycle is shown in Fig. 3. The material properties used in the simulation are contained in Table 1. Appropriate material models from the literature (Arhenius equations) were used to define the cure rate (as function of heat of reaction and temperature) and the viscosity (as function of degree of cure and temperature) for the H3501-6 resin system.
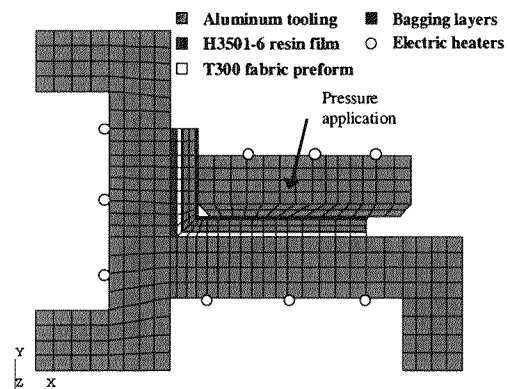

Fig.2 : The EE model with other details

Component	k	C_p	ρ
Preform	8.4	712	1790
Resin Film	0.167	1260	1260
Tooling	120	900	2660
Bagging	0.069	1256	356

Where-

k = Thermal conductivity (W/m.K)

C_p = Specific heat (J/kg.K)

ρ = Density (Kg/m^3)

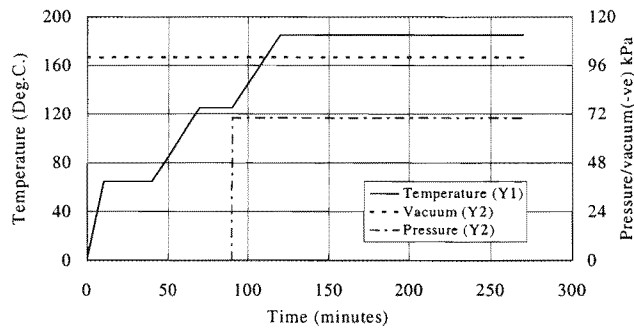**Table 1.** : Material properties used

Fig. 3 :The employed cure cycle for the L-section.

Fig. 4 : Contours of FILL factors in the preform.

The contour plots of the *FILL* factors, depicting impregnation patterns in the whole preform, are presented in Fig. 4. The dark region shows the resin saturated preform. The plots of the *UNFILL* factors for the film are shown in Fig. 5. The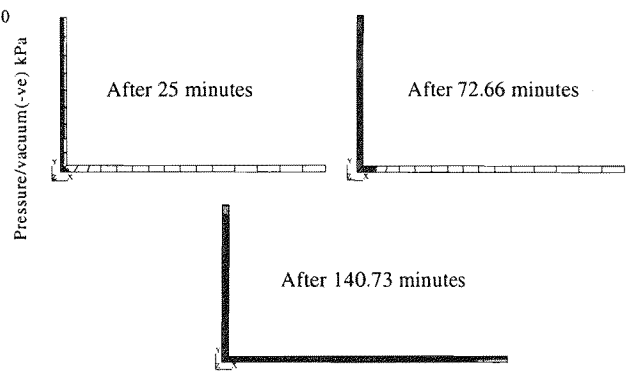y represent the simulated movement of resin within the resin film. The temperature, viscosity and degree of cure profiles within the preform are presented in Fig. 6. The timings chosen for these plots are such that there is distict variation in the distribution of parameters for presentation purposes.
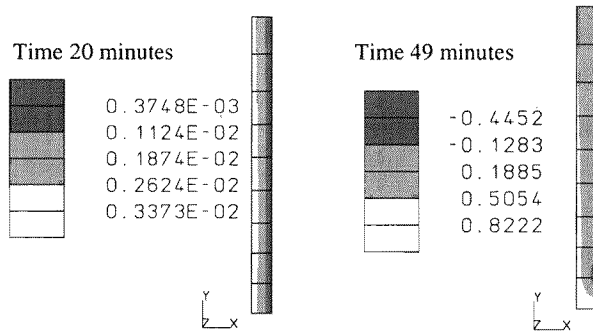

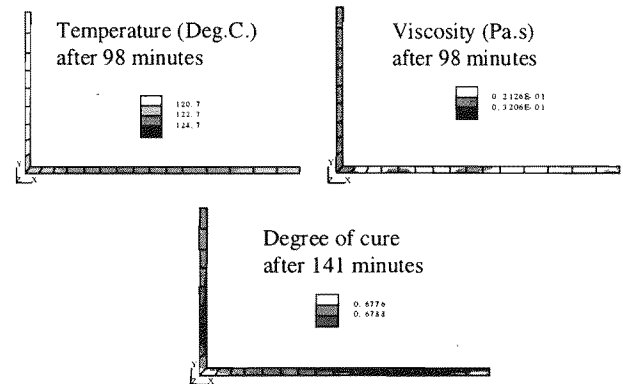**Fig. 5** : Plots of UFILL factors for the resin Film.

Fig. 6 : Temperature, viscosity, and degree of cure profiles in the preform.

6.CONCLUSION

The presented results demonstrate that the developed numerical procedure can be successfully employed to model the fabrication of advanced composite components by *RFIP.*

7.ACKNOWLEDGEMENTS

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