NUMERICAL MODELLING OF THE FILAMENT WINDING PROCES

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SUMMARY

A framework composed of several building blocks that allows the simulation of the filament winding process is described. The physical and thermo-chemical phenomena interacting at the layer/laminate level together with analytical description of the compaction and consolidation mechanisms were modelled and incorporated in finite element software.

Keywords: filament winding, consolidation, compaction, process model

INTRODUCTION

The filament winding process is a manufacturing technique in which a resin-impregnated continuous filament (or tape) tow is wound over a rotating mandrel. The synchronized movement of both the mandrel and the delivery head accomplishes the precise positioning of the fibres on the mandrel surface, leading to the desired geometric pattern. The ability to control of the process variables may allow improvements in the final geometry of the component, the process optimization and the strength of wound parts.

In order to develop the global process model, several analytical descriptive formulations of the physical and thermo-chemical phenomena, taking place during the processing period, were established together with their numerical implementation. The main outputs of the developed model are the consolidation pressure, degree of cure of the resin, viscosity of the resin, temperature in the laminate, layer position, fibre volume fraction, strains and stresses at every instant. The description of the phenomena acting at the layer/laminate level together with the modelling strategy is presented in the following items.

MODELLING APPROACH

The overall strategy is illustrated in the case of hoop winding (Fig.1). Therefore, the phenomena to model are assumed to occur in one dimension, along the radial direction across the laminate's thickness. The physical and thermo-chemical phenomena included are: the radial pressure due to the winding fibre's tension, the resin flow, the resin mixing of adjacent layers, the fibre bed compaction, the degree of cure and the viscosity of the resin. The layer position, fibre volume fraction, strains and stresses are updated accounting for those phenomena.

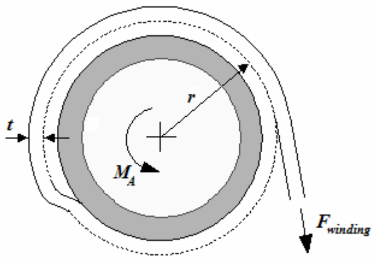

Figure 1 - Cross-section schematic representation of circumferential (hoop) winding

The radial pressure due to the winding tension, generated at the inner interface of a layer being wound, is given by

$$p_r = \frac{F_{winding}}{r\ b} \ , \tag{1}$$

where $F_{winding}$, r and b are the winding force, the radial position and the bandwidth, respectively. The resin radial flow is modelled through a Darcy's type equation for flow in porous media, with the resin radial velocity being calculated as follows [1][2][3]

$$\dot{u}^r = -\frac{S}{\mu}\frac{d\,p}{dr} \ , \tag{2}$$

where S, μ and $\frac{d\,p}{dr}$ are, respectively, the fibre bed permeability, the resin viscosity and the radial pressure gradient across the thickness.

The resin mixing of adjacent layers, the viscosity and the fibre volume fraction are computed from the knowledge of resin radial velocity. The governing equation of the cure kinetics of the resin was taken from literature [4][5]. Thermoset and thermoplastic resin systems are considered and modeled. The stress-strain relationship for each layer is computed in a local coordinate system. It includes specific physical features inherent to the filament winding process. The overall strategy was applied to axissymetric geometries and the effects of winding parameters on the component quality are discussed.

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References

1. A. Banerjee, L. Sun, S. C. Mantell, D. Cohen, *Model and experimental study of fiber motion in wet filament winding*, Composites Part A **29A**, pp.251-263, 1998.

2. T. G. Gutowski, Z. Cai, S. Bauer, D. Boucher, J. Kingery, S. Wineman, *Consolidation experiments for laminate composites*, Journal of Composite Materials **21** (1987), pp. 650-669.

3. P. Hubert, A. Pourtsartip, *A Review of Flow and Compaction Modelling Relevant to Thermoset Matrix Laminate Processing*, Journal of Reinforced Plastics and Composites **17** (1998), pp. 286-318.

4. W. I. Lee, A. C. Loos, G. S. Springer, *Heat of Reaction, Degree of Cure and Viscosity of Hercules 3501-6 Resin,* Journal of Composite Materials **16** (1982), pp. 510-520.

5. S. J. Ng, R. Boswell, S. J. Claus, F. Arnold, A. Vizzini, *Degree of Cure, Heat of Reaction and Viscosity of 8522 and 977-3 HM Epoxy Resin*, Technical Report, Naval Air Warfare Center Aircraft Division, Maryland, 2000.