

A STOCHASTIC APPROACH TO MODELING THE EFFECT OF MATERIAL VARIATION IN OUT-OF-AUTOCLAVE PREPREG CONSOLIDATION

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Introduction

Out-of-Autoclave (OoA) prepregs are a more cost and energy efficient counterpart to traditional autoclave-cured prepregs due to low pressure consolidation compensated by a special, partly impregnated microstructure. Even though OoA prepregs are machine-made, material uncertainties are always present. Neglecting these inherent spatial variations in simulations is not acceptable with this technology, regarding the prepreg's sensitivity to voids. Therefore, a deterministic 2D consolidation model was embedded in a stochastic environment to account for random effects. The initially partly impregnated microstructure or the resin distribution within the fibre bed is characterized by the initial degree of impregnation (IDOI) and determined as the impregnated over total prepreg height. Preceding studies showed that particularly the IDOI incorporates uncertainties as observable in figure 1(a). Therefore, this parameter was chosen to be represented by a random field within the model, though applicable to any other parameter.

Deterministic 2D consolidation model

The 2D-model captures the interaction between air evacuation through the partly impregnated microstructure, resin flow into these areas and fibre bed compaction for unidirectional prepregs. Unimpregnated areas are considered to form a compressible, permeable layer that allows gas evacuation when vacuum is applied and is infiltrated when temperature increases. Pressure gradients govern in-plane and through-thickness resin flow velocities, while resin viscosity is time and temperature dependent. The fibre volume fraction and corresponding permeability can vary across the lamina and changes with time. Gas evacuation according to the Arafath Model [1] determines the pressure within dry areas and therefore at the resin flow front, initially determined by the IDOI. The partial differential equation obtained by the combination of several equations such as Darcy's law, continuity equations, a phenomenological derived fibre bed compaction curve and a stress equilibrium law governing load-sharing between resin and fibres is solved numerically with a backward finite difference scheme.

Stochastic approach

To describe the IDOI as a spatially varying property, a random field $IDOI(x, w)$ is introduced depending on the stochastic variable w and the space variable x . The Ornstein-Uhlenbeck process was chosen to represent this field as depicted in figure 1(b), which is a stationary Gaussian process with constant mean value and a covariance function represented by a one parameter function $C_{IDOI}(\Delta x)$. The characteristic parameters of the process are determined by CT images. To discretize the probabilistic space, a quantization of $IDOI(x, w)$ was conducted by a

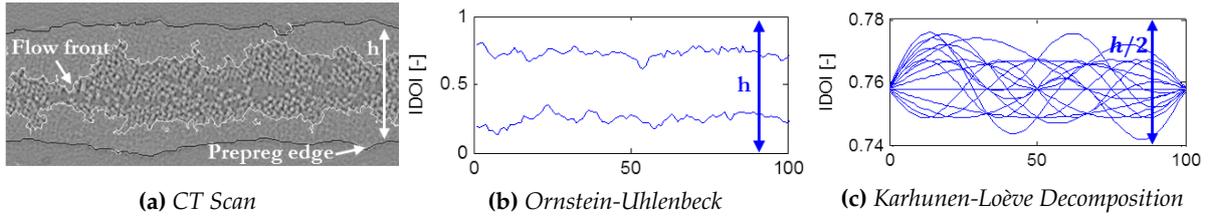


Figure 1: Discretization of the random field.

Karhunen-Loève truncation (figure 1(c)) to approximate the random variable by finitely many orthogonal basis functions determined by the covariance function $C_{IDOI}(\Delta x)$. The model's output is approximated by a linear combination of second order Hermite Polynomials as a function of the uncertainty parameters. Furthermore the probabilistic collocation method (PCM) is used to determine the coefficients of the polynomial chaos expansion by solving the above described 2D model for different sets of collocation points. In [2] it was shown that the PCM can deliver similar results to the computationally expensive Monte Carlo simulations. Statistical moments and probability density functions can be calculated directly from the coefficients of the polynomial chaos expansion.

Results and discussion

According to [3], the void content of OoA parts after consolidation is expected to change with reduced ambient pressure. The model's reply to different process conditions is summarized in table 1 and compared to [3] for a preliminary assessment of the model. Note, that the overall trend is in compliance but the experimentally determined void content is lower than calculated values despite the model neglecting voids arising through other phenomena. This is assumed to arise from disregarding physical side effects e.g. capillary forces which are subject of further research.

Table 1: Stochastic void results of the consolidation model compared to experimental data.

	μ	σ	μ [3]
Full Pressure	0.431%	0.021%	0.002%
75.5% Pressure	0.540%	0.020%	0.031%
55.0% Pressure	0.891%	0.055%	0.177%

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References

- [1] A. Arafath, G. Fernlund, Gas Transport in Prepregs: Model and Permeability Experiments, In: *17th International Conference on Composite Material, Edinburgh, UK*, pages , 2009
- [2] L. Shi, J. Yang, D. Zhang, H. Li, Probabilistic collocation method for unconfined flow in heterogeneous media, *Journal of Hydrology*, 365, 1-2: 4–10, 2009
- [3] T. Centea, P. Hubert, Out-of-autoclave prepreg consolidation under deficient pressure conditions, *Journal of Composite Material*, : , 2013