

A Consistent Environment for the Numerical Prediction of the Properties of Composite Materials

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Introduction

Composite materials with polymer matrix play an important role in various industries such as aircraft, energy and naval industry. Considering the challenging aspects of composite manufacturing e.g. increasing of part complexity, requirements for short development time or overall cost reduction, the manufacturing process simulation (MPS) becomes an important role for the process design.

In general composite materials consist of two different materials – an embedding phase (e.g. polymer matrix) and a reinforcement phase (e.g. Filler, short or long fibre). Fibre reinforcement polymer composites (FRPC) are manufactured by different technologies that can be classified into 2 groups of dry fibre or prepreg based process family. In the case of thermosets polymer the curing step remain common for both groups. The large difference of physical properties of the involved material leads to the complexity of the process, also denoted by the modelling approaches.

The MPS can help to mark more efficiently by providing key information at an earlier design stage. The present paper deals with an approach of a tool which function consists into the numerical prediction of physical properties as well as the optimization of process parameter based on a parametric modeling approach. In the course of high flexibility the tool offers also the possibility to solve multiscale applications. The architecture of the tool called CHAMAELEON is shown in Figure 1.

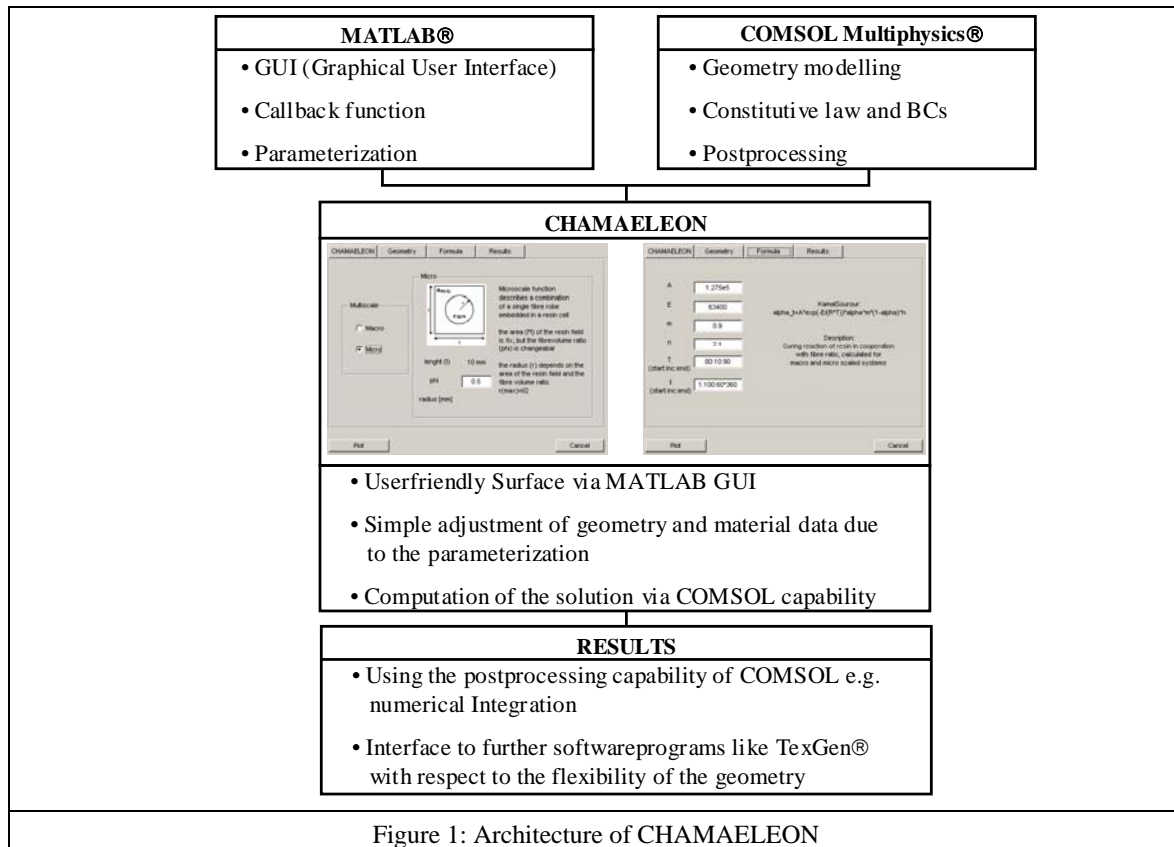


Figure 1: Architecture of CHAMAELEON

CHAMAELEON combines the features of MATLAB® and COMSOL Multiphysics®. The GUI (Graphic User Interface) of MATLAB® enables the customized settings of the problem to be solved or of the property to be computed respectively. The parametric geometry definition offers the possibility to investigate the sensitivity of a given property such as the dependency of the thermal conductivity from the fibre content. The input data from the GUI are then used to solve a field problem within the COMSOL environment. The calculation made in COMSOL are used in the sense of a numerical homogenization that is the final properties of the defined representative value element (RVE) are obtained by a numerical integration of the subdomain value of each constituent.

Use of COMSOL Multiphysics®

The principle of the numerical homogenization is demonstrated by solving the heat transfer problem. At the microscale, the problem consists into predicting first the temperature distribution within a RVE and in a second step to calculate the resulting thermal conductivity. For this purpose the heat transfer module of COMSOL Multiphysics is used (Equ.1).

$$\text{Heat Transfer by Conduction} \quad \rho C_p \frac{dT}{dt} - \nabla \cdot (k \nabla T) = Q \quad \text{Equ.1}$$

At the macroscale, the computing domain consists into a section through the system mould and laminate (assembly of single plies). The thermal properties computed at the microlevel are used as input for the laminate. The exothermic curing reaction of the resin is modeled by an ordinary different equation 1st order from Kamal Sourour type (Equ.2):

$$\frac{d\alpha}{dt} = (k_1 + k_2 \cdot \alpha^m)(1 - \alpha)^n \quad \text{Equ.2}$$

where α is the degree of curing and m, n are the reaction orders. k1, k2 denote the temperature dependency of the reaction and are given by an Arrhenius approach (Equ.3):

$$k_i = A_i \cdot \exp\left(\frac{-E_i}{RT}\right) \quad \text{for } i=1,2 \quad \text{Equ.3}$$

Equ.2 has been implemented into COMSOL by using the PDE general mode (Equ.4):

$$e \frac{\partial^2 u}{\partial t^2} + d \frac{\partial u}{\partial t} + \nabla \cdot \Gamma = F \quad \text{Equ.4}$$

and by identifying the coefficients as follows:

$$e = 0, \quad d = 1, \quad \Gamma = 0, \quad F = (k_1 + k_2 \cdot \alpha^m)(1 - \alpha)^n$$

As output from the calculation, the temperature at various locations over the entire process time are obtained and automatically plotted.

Expected Results

The postprocessing capability of COMSOL enables a customized interpretation and representation of the results. Figure 2a and 2b demonstrate typical results computed by CHAMEALEON. Concerning the microscale case Figure 2a shows the comparison of the numerical and analytical results of the effect of the fibre content ϕ on the thermal conductivity of the composite λ_{comp} . As can be seen a good agreement between analytical and numerical prediction has been obtained.

Figure 2b represents the macroscale solution. It illustrates the temperature evolution of the tool as well as of the composite material with different fibre content values during the curing process. The interpretation of the predicted temperature evolution enables the optimization of the process set-up.

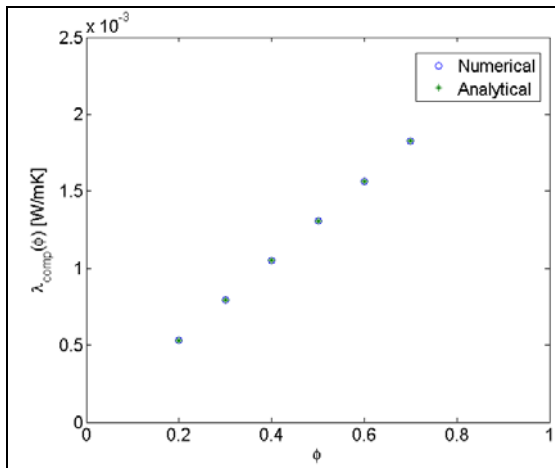


Figure 2a: Microscale
(Thermal Conductivity
as function of fibre content)

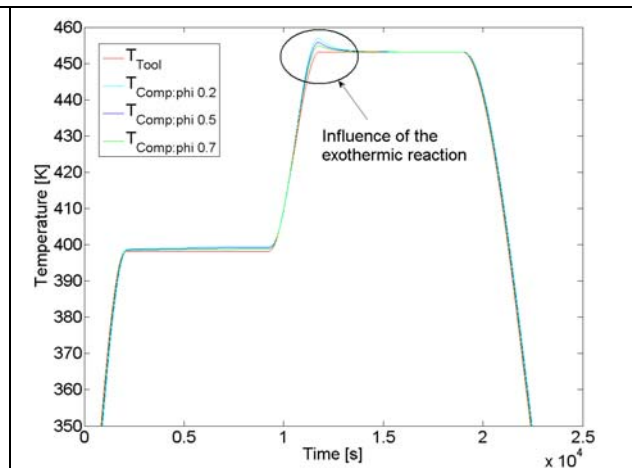


Figure 2b: Macroscale
(Influence of the exothermic reaction
on the temperature evolution)

Conclusion

The program CHAMEALEON has been designed especially for users interested on fast investigation of the influence on global laminate properties as well as on the optimization of the process parameter (heating and cooling rates). The principle of CHAMEALEON depicted in this work by the thermal properties can be easily extended to other physical properties like moisture behavior, mechanical or electrical properties. Compared with the classical way of process modeling, the use of CHAMEALEON can help to reduce the modeling effort on a significant manner.