Kurzfassung

In der vorliegenden Arbeit wird die methodische Anwendung der Harzinjektionssimulation beschrieben. Hierzu werden drei Hauptaspekte betrachtet.

Zunächst werden die im verwendeten Simulationsmodell getroffenen Vereinfachungen auf ihre Auswirkung auf die Anwendung der Simulation untersucht. Für geringe Fließgeschwindigkeiten bis zu 3 cm/s konnte das Gesetz von D'Arcy als grundlegendes Fließmodell in kommerziell verfügbaren Simulationsprogrammen verifiziert werden. Die Vereinfachung eines Punktangusses als ein Ein-Knoten-Modell ist hingegen nicht zulässig, da dadurch eine Singularität im Modell entsteht. Durch ein vierknotiges Angussmodell kann dieses Problem beseitigt werden.

Im zweiten Teil wird die Beschaffung der Eingabeparameter für die Simulation diskutiert. Für die besonders schwierig zu messende ungesättigte Permeabilität in Dickenrichtung wurde ein Modell entwickelt, um diese Permeabilität aus den gesättigten Werten zu bestimmen, die in der Regel wesentlich einfacher zu ermitteln sind.

Der dritte Teil der Arbeit beschäftigt sich mit der methodischen Modellauswahl zur Optimierung des Zeit- und Kostenaufwandes bei der Simulation. Es werden Kriterien für die Modellauswahl entwickelt und diese anhand zweier sehr unterschiedlicher Beispiele angewendet. Hierfür wird an einer PKW-Stirnwand für das RTM-Verfahren und einem Hilfsspant eines Flugzeuges für das RFI-Verfahren die methodische Vorgehensweise bei einer Harzinjektionssimulation demonstriert.

Abstract

In this thesis the methodical application of liquid composite molding simulation is discussed. The main focus is on three aspects: In the first part simplifications of the simulation model and its influence on the application of the simulation will be shown. The determination of the input parameters is the topic of the next part. The third section deals with the methodical choice of simulation models to optimize cost and time schedule. Using two quite different examples the proceeding in liquid composite molding simulation is explained.

Basically the simulation could be verified. For both the unidirectional and the two directional flow for lower and middle flow velocities a good correlation of simulation and experiment was found. At velocities above 3 cm/s the fit of the simulation results is significantly reduced. It can be assumed that increasing inertia and friction effects influence the experimental results and therefore the creeping flow assumption in D'Arcys law cannot be assumed to be valid. At higher flow velocities of the injected fluid the simulation model has only a limited validity.

An interesting field was identified modeling an injection point in flow simulation. Using the FEM it should not be described by a single node as one will obtain a singularity and therefore unstable simulation results. To avoid this problem the injection port can be modeled by using four nodes. This description of the injection gate provides sufficient results.

A challenge in simulation technique is the determination of input parameters. Beside some very easily obtained parameters such as injection pressure, viscosity of resin or thermal properties of the used components the permeability of the reinforcement is a key value. Especially in through thickness direction the for simulation very important unsaturated permeability of the fiber preform is very difficult to measure due to the short flow length and the complicated access to the flow front. However, the saturated permeability is comparatively easy to determine.

For unidirectional preforms a model was developed which is able to predict unsaturated permeability derived by its saturated value. The model is based on an simple parallel and serial set-up of single permeabilities of flow channel and fiber tows. The different values of permeabilities in a saturated as well as an unsaturated case are resulting thereby from a compression of the fiber tow due to the surrounding liquid pressure which leads to an expansion of the inter tow space. In order to describe this effect a dimensionless compression factor κ is introduced which relates the volume of the compressed tow to the initial state. When the flow occurs in fiber direction this effect leads to a raising permeability due to the dominance of the flow channels in the total permeability while in the case of flow in the perpendicular direction a reduction can be observed because of the overall reduction of the permeability caused by the reduction of the fiber tow permeability due to compression. This is due to the fact that in this case the flow channels do not help the spread of the fluid in flow direction. The model prediction for saturated and unsaturated flow could be verified in the experiment. Under the assumption that for the flow in thickness direction we have a similar flow mechanism as for the in-plane flow of the material perpendicular to the fiber direction, the values for the unsaturated permeability can be calculated from the values for the saturated permeability with this model.

A critical parameter of this model is the compression factor κ, which is a function of the fiber volume fracture and the fluid pressure. For further developments of the model this dependence has to be analyzed. The aim is here to find a model for the compression of the fiber tow, so that the experimental determination can be replaced by a calculation model.

In order to simplify the decision for the dimension of the Finite-Element-Model, an analytic formula has been developed for the approximated error between the used 2D model and the 3D model. As parameters in this formula we have the relative flow path (flow path related to the part thickness) and the ratio of the in-plane permeability and the permeability in thickness direction. The formula is valid for an injection line with impregnation in thickness direction of the perform.

In further works these results will have to be verified and adjusted for injection points. A problematic aspect is the computation time as a complete three dimensional model is required.

Finally the methodical optimization of two injection processes will be demonstrated on two examples taken from practice. In the first one (front wall of a car) the aspect of an error tolerant simulation will be discussed. While the simulation seemingly yields an optimal solution under the assumption of constant input values, significant short comings can be shown for the necessary variation of the parameters due to measurement errors or qualitative oscillations. Only when the range of all input parameters is considered in simulation a reliable statement about the stability of the process can be made. Furthermore, the possibilities of the injection system layout and of the process optimization by adjustment of the process control will be discussed.

In the second example possibilities are shown to make statements about process optimization via simulation despite unfavorable boundary conditions. The filling behavior of a center fuselage side skin of a plane, which was produced with the RFI-technique, was calculated with the use of a 2D calculation. For this a customized algorithm was programmed which takes into account a simplified model of RFI. With the help of this optimization the filling time could be reduced from 168 s to 5.3 s.

All in all the process simulation of resin injection techniques will be able to contribute fundamentally to process optimization. The major shortcomings still exist in the determination of parameters, especially in the determination of the permeability. In order to establish the simulation in industry it will be necessary to do more research on methods for determination of permeabilities without experiments in the preliminary stages of the simulation. Only under these requirements the simulation will be attractive for the user.