Kurzfassung

In der vorliegenden Arbeit wird eine Simulation der Prozesskette der Harzinjektionsverfahren vorgestellt. Dazu wird der Gesamtprozess in drei unterschiedliche Einzelprozesse unterteilt: Drapierung, Injektion und Aushärtung.
Die für die gesamte Prozesskette grundlegende Simulation stellt die Drapiersimulation dar. Diese liefert die Faserorientierungen des drapierten Bauteils, die für die im Anschluss durchzuführende Injektionssimulation entscheidend sind.

Um die Ergebnisse der Drapiersimulation zur Simulation der Fließvorgänge zu nutzen, wird eine Schnittstelle entwickelt. Diese wandelt die Ergebnisse der Drapiersimulation in ein für die Injektionssimulation nutzbares Format um und berücksichtigt deren spezielle Anforderungen an das Simulationsmodell.

Zur möglichst effizienten Durchführung der Harzinjektionssimulation wird das Modell in einzelne Zonen mit gleichen Permeabilitätswerten und Faservolumengehalten unterteilt. Um den Einfluss der Gewebescherung auf das Fließverhalten von Fluiden zu ermitteln, werden Fließversuche mit gescherten Geweben durchgeführt und verifiziert.

Die Funktionsweise der Schnittstelle und die Anwendbarkeit der gemessenen Materialkennwerte werden an einer Kugelhalbschale demonstriert und durch Versuche verifiziert. Anhand einer Armaturentafel wird der Nutzen der Schnittstelle für die Fließsimulation komplexer Bauteile gezeigt.

Die Prozesskette wird mit der Simulation der Aushärtevorgänge abgeschlossen. Dazu wird ein reaktionskinetisches Modell nach Kamal-Sourour für ein ausgewähltes Epoxidharz erstellt. Anhand einer Rippenstruktur wird die Aushärtesimulation verifiziert. Durch die Aushärtesimulationen kann der Einfluss des Faservolumengehalts sowie der Bauteildicke auf die während des Aushärtevorgangs erreichbaren Maximaltemperaturen ermittelt werden.

Abstract

Liquid composite moulding (LCM) is an efficient process for manufacturing polymer composite structures. During LCM a liquid thermoset resin is injected into the mould cavity containing a pre-placed dry fabric preform. In the last step of the process the resin cures and afterwards the part can be removed from the mould. Due to relative low injection pressure applied in processing this technique is expected to offer potential for cost reduction in the fabrication of large parts of complex shape. However, in practice, much time is spent for optimising processing parameters and properly designing the mould in order to avoid problems such as void formation and dry spots. The common trial and error tactic to determine optimised parameters increases time and costs for an optimal process configuration. Thus simulation will help to speed up the development process saving cost and time.

When producing double curved parts the angles between warp and weft fibres of the fabrics change and influence the permeability of the fabric as well as the preferred direction of flow through the fabric during the injection phase. Further on these shearing effects increase the fibre volume fractions and therefore less resin is available in the correspondent areas. This leads to different results of the curing process in the sheared areas compared to the curing process in the unsheared areas.

Opposite to the current LCM simulation technique where only the injection process is simulated, this work presents the simulation of the three single processes and combines them in an appropriate way to improve the simulation results.

First draping simulations are performed. Therefore, the shear behaviour is investigated. These results are used in the draping simulation in order to obtain the fibre orientations of the warp and weft fibres. The draping results are verified by comparing them with the corresponding parameters of parts formed.

In order to use the results of the draping simulation in the flow simulation an interface is developed that transforms the result files obtained from the draping simulation into a file format suitable for the flow simulation. The mode of operation of this interface is illustrated. First a standard file format is generated to combine the shearing angles and the node locations delivered by PamForm™. A programme is developed that reads the node locations, the shear angles and the fibre orientations at the end of the draping simulation and creates a new file usable for the flow simulations. Further on several features are implemented in the new model as for example the automatic generation of a circular inlet with a defined diameter and the adjustment of the draping model to the model for the flow simulation concerning the fitting of the geometry model. In order to consider the changes of permeability and fibre volume fraction in sheared areas, zones are defined which represent areas of the same fibre volume fractions and the same permeability. Flow experiments on sheared fabrics are performed to get information about the flow behaviour. The permeability values of the sheared fabric are calculated by observing the position of the flow front over time and the application of Darcy's law. This material behaviour is implemented into a commercially available LCM-simulation software which is verified first using a simple plate with a sheared fabric, then using a double curved structure (hemisphere) with draped fabric. After the verification based on the hemisphere another part is chosen to show the ability of the interface to deal with more complicated geometries.

To obtain the input parameters for the cure kinetic model of Kamal-Sourour an epoxy resin is characterised using DSC. The validity of this model is verified by comparing the cure process of a flat sheet with a rib with the corresponding simulation results. To determine the influence of the fibre volume fraction on the maximum temperature, a cure simulation of the hemisphere with the zone distribution is performed. Cure Simulation on a flat plate are done to quantify the influence of the thickness of the part on the maximum temperature in the part.