Kurzfassung

Das Ziel der vorliegenden Dissertation ist es, für den innerhalb der Faserkunststoffverbunde etablierten Liquid Composite Molding (LCM) Herstellungsprozess, eine optimierte Preformherstellung aus unidirektionalen (UD) Verstärkungsfasern zu entwickeln. Dies beinhaltet auch das lokale Verstärken einer textilen Preform. Der ausschlaggebende Prozess ist hierbei der Preform-Prozess, da dieser Kostentreiber innerhalb der LCM-Prozesskette ist, in welchem die Verstärkungsfasern zu einem trockenen, transportfähigen und meist flächigen Faserrohling verbunden werden.
Innerhalb des hier entwickelten Preformingprozesses werden Kohlenstofffasern, sogenannte Heavy Tows mit einem pulverförmigen Bindersystem eingebracht, erhitzt und mittels Endeffektor beim Ablegen konsolidiert. Die für den Prozess benötigten Module und Systeme wurden vor der Online-Bebinderung zuerst an einem separaten Offlinebebinderungsprüfstand montiert. Mittels dieses Offlinebebinderungsprüfstandes war die Optimierung und Analyse der einzelnen Module und Systeme durch die Herstellung eines kontinuierlich bebinderten Rovings (Halbzeug) außerhalb der diskontinuierlichen Online-Bebinderung möglich. Zugleich wurden mit dem Offlineprüfstand Halbzeuge mit unterschiedlichem Bindergehalt und unterschiedlichem Bindertyp hergestellt um einen Einfluss des Bindergehaltes als auch des Bindertyps auf die Eigenschaften der Preform und des infiltrierten Bauteiles zu analysieren. Die Analyse der Versuche zeigte deutlich, dass die Wahl des Bindertyps bei gleichbleibender Infiltrationsmatrix einen signifikanten Einfluss auf die Performance des Bauteils hat, wohingegen die Bindermenge tendenziell einen untergeordneten Einfluss zeigt. Nach der Sicherstellung der Funktionsfähigkeit der Module wurden diese an ein robotergestütztes Ablegesystem zur Online-Bebinderung installiert. Die Applizierung der Binderpartikel innerhalb der Online-Bebinderung erfolgt temporär während des Ablegeprozesses. Zur Demonstration der Funktionsfähigkeit wurde eine quasiisotrope Glasfaserpreform lokal mit den Kohlenstofffasern verstärkt. Die hergestellte ebene Preform wurde im Anschluss erwärmt, kompaktiert und in eine 3 dimensionale Preform umgeformt.
Den Abschluss der Arbeit bildet eine Wirtschaftlichkeitsbetrachtung des entwickelten Prozesses im Vergleich zu zwei „State of the Art“ Preformherstellungsprozessen. Hierbei konnte gezeigt werden dass die Kosten des gesamten Bauteiles um 3,7 % sinken unter Anwendung des neu entwickelten Verfahrens der Online-Bebinderung.

Abstract

Target of this thesis was the optimization of the preform manufacturing for the production of fiber reinforced plastics by established Liquid Composite Molding (LCM) manufacturing processes. Since the preform is the main cost driver within the LCM process chain particular attention needed to be paid to the preform process in which the reinforced fibers are combined to a dry, transportable and mostly planar fiber preform.

After analyzing current preform manufacturing processes all required process techniques are described in the “State of the Art” section. This is the basis for the development of all essential units within the new established preforming manufacturing chain. During the developed preforming process carbon fibers - so-called heavy tows with 50,000 fibers - are applied with a powdered binder system, heated up and consolidated with an end effector during the fiber placement. Prior the establishment of the online bindering process the different modules and systems required for the process (manufacturing) were developed, build-up, and installed on a separate offline bindering test rig. To optimize and analyze the individual modules a continuous bindered roving (semi-finished product) was produced by the use of this offline bindering test rig. As the most critical challenge the Binder-Conveying-Unit (B-C-U), which supplies the powder binder particles in an air flow from where they are applied to the roving, was proved. Depending on the process speed which was set to 15 m/min, the B-C-U was designed to achieve a binder content from 1 to 10 mass %. The B-C-U is based on a gear-conveying system which is driven by a stepper motor with gear reduction and controlled by a CNC-based software. Furthermore, a vibration generator (air vibrator) causes the complete B-C-U to vibrate. The oscillation frequency and force can be adjusted by changing the air pressure. This prevents an agglomeration of the powder binder inside the binder storage hopper and supports the binder particles separation. Depending on the rotation speed of the gear and the adjustable distance between the gear and the wall (slide bar) the binder output is variable. The distance between the wall and the slide bar is fixed to 0.2 mm for all tests. Tests with different binder materials showed a linear output behavior depending on the rotation speed.

During the offline bindering process the binder particles were applied to the roving inside a Binder-Application-Unit (B-A-U). The binder particles were heated over the melting point with a hot air stream supported from an electric air heater to increase the adherence of the particles on a roving (semi-finished product). Similar semi-finished parts were produced with different contents and types of binder by this offline bindering test rig. They were used to analyze the influence of the binder content and the binder type on the properties of the preform and the infiltrated component.

For the binder roving placement a robot assisted placement system with an optimized placement head was used. For the above mentioned analysis different preform geometries with variation of the lay-up configuration were manufactured. Tests with the dry preforms were carried out regarding the stiffness (dynamic mechanical analysis), the compaction behavior and the infiltration (permeability tests in-plane and out-of-plane). A part of the particular preforms were infiltrated with resin for mechanical characterization. A Vacuum Assisted Resin Infusion (VARI) process was used as LCM-Process. With the infused preforms ILSS and 3 point bending test series were carried out. The analysis of the tests clearly showed that the choice of binder types has a significant impact on the performance of the infused component, whereas the binder content tends to have a minor influence. The K3 permeability (through- the-thickness) is also influenced from the binder content. The results show a decreasing of the permeability depending on higher binder content.

After ensuring the functionality of all components and after the manufacturing of the semi-finished material, the required modules were installed on a robot-assisted placement system. The application of binder particles within the online bindering is selectable during the placement process. For this step a Binder-Start-Stop-Unit (B-S-S-U) was installed just before the binder application nozzle. With this system a precise binder application between the incoming dry fibers and the mold or already layed up preform (nip-point) is possible. Also a clocked binder application for the reduction of the overall binder content (easier impregnation) and an easier preform draping is possible.

For the verification of the online bindering placement system a quasi-isotropic glass fiber preform was locally reinforced with carbon fibers. For the manufacturing of the glass fiber preform, a binder fleece was stacked between each of the five layers of glass fabrics. On top of the glass preform a local reinforcement (crossing structures) with carbon fibers was attached under the usage of the online bindering system. The so produced local reinforced preform is than ready for the impregnation or a subsequent preform draping process. To verify the ability of draping some of the produced flat preforms were heated up over the melting temperature of the binder particles on top of a 3D mold. After the temperature decreased the 3D preform is prepared to store or for the impregnation process.

Concluding an economic feasibility study of the developed process compared to "State of the Art" preform manufacturing processes is presented. As reference preform manufacturing processes the Tailored-Fiber-Placement Process and the manufacturing with crimp or non-crimp fabrics were carried out. It has been demonstrated that the costs of the entire component can be reduced by 3.7 % using the newly developed method of online bindering.