Kurzfassung

Bei der Herstellung von Faser-Kunststoff-Verbunden durch Harzinjektionsverfahren wird ein textiler Vorformling, die Preform, mit einem Harzsystem imprägniert und anschließend ausgehärtet. Die Erzeugung der Preform, auch Preforming genannt, beinhaltet dabei eine Vielzahl an Arbeitsschritten, welche maßgeblich die Kosten des herzustellenden Bauteils bestimmen. Die Automatisierung des Preformings birgt daher ein enorm hohes Potential zur Kostenreduzierung. Im Rahmen dieser Arbeit wurde deshalb ein neues Preforming System entwickelt, welches die kontinuierliche Herstellung von Profil-Preforms aus textilen Halbzeugen ermöglicht. Erstmalig wurde dabei zur kontinuierlichen Fixierung die Nähtechnik verwendet, welche ein energie- und zeiteffizientes Preforming zulässt. Allerdings hat sich bei der Herstellung von Profil-Preforms mit unterschiedlichen textilen Halbzeugen gezeigt, dass die maximal erreichbare Prozessgeschwindigkeit ohne relative Textilschädigung variiert. Ursache hierfür ist das Textilverhalten während der Formgebung. Durch die Wahl geeigneter Material- und Prozessparameter besteht allerdings ein hohes Potential, einen Preforming Prozess zu optimieren. Daher war es das Ziel dieser Arbeit, Richtlinien für Material- und Prozessparameter zu entwickeln, die sowohl eine robuste als auch effiziente Preformherstellung ermöglichen.

Als kritische Textileigenschaften wurden das Kompaktierungs-, das Reibungs- und das Biegeverhalten identifiziert. Diese wurden in separaten Parameterstudien hinsichtlich der Auswirkungen von Materialparametern (z. B. Bindungsart) und Prozessparametern (z. B. Prozessgeschwindigkeit) untersucht. Die Ergebnisse konnten anschließend in Richtlinien zusammengefasst werden, welche für eine prozessorientierte Materialauswahl oder für Prozessmodifikationen beim Preforming genutzt werden können. Bei der Übertragung auf einen Preforming Prozess muss jedoch berücksichtigt werden, dass sich Effekte verursacht durch Kompaktierung, Reibung und Biegung in Abhängigkeit des Faservolumengehaltes der Preforms überlagern können. Daher wurden anhand einer weiteren Studie dominierende Textileigenschaften in Abhängigkeit des Ziel-FVG der Profil-Preforms beim entwickelten Preforming Prozess identifiziert. Abschließend wurden die entwickelten Richtlinien verifiziert, indem sowohl eine prozessorientierte Materialauswahl als auch prozessseitig eine Vorkompaktierungseinheit validiert wurden.

Abstract

During the manufacturing of fiber reinforced polymer composites via Liquid Composite Molding a predefined fiber structure (preform) is impregnated with a resin system and subsequently cured. The production of semi-finished textile preform products includes a number of steps which largely determine the costs of the final component. Therefore, automation of the preforming process represents an extremely high potential for cost reduction.

To overcome the deficits of current preforming approaches, a new continuous profile preforming system was developed in the frame of this work. For the first time, stitching technology was applied to fix continuously formed semi-finished textile products which increased the efficiency of preforming. Due to this development, it was possible to double original production speed limits from 2 m/min to currently 4 m/min.

However, in the production of profile preforms with different textile semi-finished products it was necessary to vary the maximum production speed to prevent damage to the different textiles. This applies particularly when forming the textile semi-finished products. By choosing suitable materials and process parameters, there is a high potential to improve the preforming process and its efficiency. Therefore, the aim of this work was to develop material and process parameter guidelines which allow both stable and efficient preform production.

Friction, bending, and compaction behavior were identified as the most critical textile characteristics. In a first step, separate parametric studies were performed in order to investigate the effects of material (e.g. single-ply superficial density) and process parameters (e.g. process speed) on the friction, bending, and compaction behavior. The goal of this investigation was to identify dominant parameters to allow a process-related material selection and process modifications. Concerning the material parameters, five carbon fiber non-crimped fabrics (NCF) were examined, which differed by not more than two parameters. To investigate the effects caused by process parameters, processing speed, normal load, tool surface, number of testing cycles and testing directions were varied.

The results of the compaction study revealed that doubling the superficial density of single plies decreases the compaction forces to reach a fiber volume content of 50 % by 80 %. In this context, less amount of stitching yarns and bigger yarns bundles decrease the compaction forces. Especially for multi-ply preforms, the stitching yarns tend to superimpose which leads to an increase of compaction force. But selective tailoring of stacking sequences can decrease the compaction forces. For example, by turning individual plies within one stack, nesting possibilities can be achieved to reduce the compaction forces by up to 42 %, while the mechanical performance is almost not affected. Concerning the process parameters, ten consecutively applied compaction cycles reduce the compaction forces by up to 87 %.

The friction study revealed that coefficients of friction of carbon fiber NCFs vary due to changing surface structures at different fiber volume contents. Furthermore, tool-textile friction is half of the friction forces between two NCF samples. When the single-ply superficial density of the NCF is doubled, the dynamic friction forces are reduced by 80 %. The type of stitching influences the friction behavior as well. For example, NCFs with a pillar stitching pattern lead to higher dynamic friction forces on the bottom side of the NCF compared to its top side. Additionally, by varying the process speed no relevant effect on the friction behavior could be observed.

In the bending study, the bending stiffness of the dry NCFs were measured using the cantilever test set-up (single-ply tests). It was found that the bending stiffness of ±45°-NCFs is up to 85 % lower compared to 0°/90°-NCFs and halving the superficial density of single plies led to a decrease of 77 %. By utilizing a new test set-up it could be shown that a quasi-linear relationship between the number of plies and the bending force exists, whereby each additional ply increased the bending force by 27 % in the considered range. However, at an equal superficial density of a multi-ply stack, 6-ply preforms require less bending forces than 3-ply preforms. In this context, yarn bundling is the dominant material parameter, which depends on the stitching type used in the NCFs.

The results of the studies were summarized and transferred into guidelines (friction, bending, and compaction). These guidelines can be utilized for preforming design to realize a process-related material selection or process modifications to increase the stability and material throughput of preforming processes. Concerning the application of the developed guidelines for a preforming process, it has to be considered that friction, bending, and compaction can have counteracting effects. However, a final parametric study has shown that the findings can be transferred to the developed continuous preforming process. The dominant textile characteristics of T-profile-preforms at different fiber volume contents could be identified which opened the opportunity to selectively vary material and process parameters in order to increase the process robustness and/or efficiency.

Finally, based on the developed guidelines, a process-related material selection and a process modification of the new preforming system were performed. With respect to the process-related material selection it was possible to reduce the continuous forming forces by approximately 24 % by increasing the superficial density of single plies as well as decreasing the stitching yarn amount. Furthermore, the integration of a pre-compaction unit (process modification) reduced the continuous forming forces approximately 20 %. Consequently, the process speed to manufacture a T-profile-preform (fiber volume content was 50 %) could be quadrupled until the initial forming force (base reference without applied pre-compaction cycles) was again reached. Accordingly, the application of the guideline was successfully demonstrated.

These insights into the textile forming behavior can be applied on both the material and process side. On the material side e.g. textile manufacturers have the opportunity to expand their product portfolio by manufacturing friction, bending and compaction optimized textile semi-finished products. On the process side, the number of optimization loops can be reduced since the used textile semi-finished products can be selected according to the expected material behavior. In existing preforming processes limitations can be overcome by a targeted adaption of material parameter.