Kurzfassung

In der vorliegenden Arbeit wurde ein Prozess entwickelt, zur Realisierung lokal, lastgerecht verstärkter Thermoplast-Hybridbauteile im Einsatzgebiet struktureller Anwendungen im Automobilbereich. Hierzu wurde effektiv ein formgebender Schritt für gewebeverstärkte Halbzeuge mit dem in-situ Tapelegeverfahren zur Aufbringung unidirektional endlos faserverstärkter Bändchenmaterialien kombiniert.

Die durch die symbiotische Ausnutzung der Vorzüge der beiden Verfahren in Kombination mit Sandwichbauweise realisierten Bauteile, zeichnen sich einerseits durch eine Reduktion des Gesamtgewichts aus und weisen andererseits ein weit höheres mechanisches Eigenschaftsprofil auf, als mit rein singulären Prozessschritten möglich ist.

Im Rahmen des ganzheitlichen Prozessansatz wurden, ausgehend von einer experimentellen und theoretischen Ermittlung, optimale Prozessparameter für das in-situ Tapelegeverfahren in Bezug auf die interlaminare Risszähigkeit zwischen den Materialpartnern, die Grenzschichtgüte beeinflussende Vorgänge ermittelt und diskutiert. Es konnte gezeigt werden, dass durch die gewählte Prozesskombination deutlich erhöhte Energiefreisetzungsraten realisiert werden können, verglichen mit Proben, welche im Autoklav hergestellt wurden. Im Rahmen umfangreicher mechanischen Charakterisierungsreihen konnte direkter Einfluss der unidirektionalen Verstärkungslagen auf das mechanische Eigenschaftsprofil der Multimaterialsysteme nachgewiesen werden. Darüberhinaus wurde das Hybridsystem erfolgreich in einer FE-Simulation abgebildet und validiert. Durch eine prozessbasierte, ökonomische Betrachtung konnte der Prozessansatz gegenüber Konkurrenzverfahren abgegrenzt und als kosteneffektiv bewertet werden.

Die Ergebnisse dieser Arbeit zeigen einen, sowohl unter mechanischen als auch ökonomischen Gesichtspunkten, sinnvollen und geeigneten Prozess zur Realisierung lokal verstärkter struktureller Faser-Kunststoff-Verbund-Bauteile mit inhomogener Lastverteilung auf.

Abstract

Nowadays, polymer-based materials play leading roles in the automotive industry. Fiber reinforced polymer composites (FRPC) based on thermoplastic matrix systems are commonly used in interior and semi-structural applications for the substitution of conventional materials like steel.

Faced to drivers for E-Mobility like austerity of resources, CO_2-legislation and among others change of ideals, the automotive industry is challenged to design products that can comply with environmental legislation in the future.

Textile as well as unidirectional endless fiber reinforced materials offer on the one hand an enormous lightweight potential and on the other hand outstanding mechanical properties to fulfill sustainable mobility concepts. Unfortunately, today, this material class plays a negligible role for mass production of semi- and structural applications due to economic reasons.

A key-driver for the successful implementation of endless fiber reinforced thermoplastics in the automotive is the reduction of the overall production- and part-costs. Traditional processes need to be adapted to fulfill the short-cycle times for large-scale production in the automotive industry. Therefore new process-routes have to be evolved. Recent developments are trying to combine two or more lightweight production methods for the realization of multi-material-systems to overcome the existing process and performance limitations.

The focus of this work is to describe a new process approach for the cost-effective build-up of hybrid structures by effectively combining a forming process of textile reinforced organic sheets with locally, load-related applied unidirectional endless fiber reinforced tapes by use of in-situ tape placement process. Compared to singular lightweight production methods, load- and at the same time weight-optimized FRPC-parts can be designed with the realized multi-material-systems. In order to optimize the bending behavior, the hybrid structure was performed as sandwich with integrated foam core.

Principal purpose of the process development presented in this thesis is a holistic approach. This includes experimental and theoretical determination of optimal process parameters, mechanical characterization as well as implementation into finite element simulation. To justify the right to exist in terms of economic viewpoint a process-based cost evaluation was performed and compared to competing processes.

Mechanical properties of the pre-chosen, commercial available material partners TEPEX® dynalite 104-RG600(x)/47%, Celstran CFR-TP PP GF70-13 and Neopolen® P-9255 were performed.

Regarding the quality of the interface zone between the material partners the energy release rate G_{IC} was chosen as indicator. By use of in-situ tape placement process with experimental determined optimal process parameters (hot gas volume flow rate: 6 Nl/min; layup velocity: 6 m/min), an energy release rate of 4 J/mm^2 could be obtained, which was twice as high compared to specimens produced in the autoclave.

3 phenomena that influence the interface behavior were determined. According to the process characteristics of the in-situ tape placement process the absence of fiber migration in the interface, the crystallite structure and molecular stretching and relaxation processes, the interface is characterized by a more ductile behavior, which results in higher value of G_{IC}.

By combining thermoforming and in-situ tape placement with predetermined optimized parameters hybrid structures were performed and mechanical characterized by static testing. Significant increase of mechanical tensile and bending properties in dependency of unidirectional reinforcing layers could be detected.

A finite element simulation that was able to predict the behavior of the multi-material-system and the sandwich-structure was implemented and verified by mechanical testing. Within the FEM analysis the fiber orientations of the base materials and the locally applied endless fiber reinforcements have been taken into account as well as the boundary behavior based on molecule stretching and relaxation phenomena by use of modified interface and contact elements between the material partners.

To evaluate the economic potential of the process approach against competing concepts a transparent, process-based cost analysis was performed, comprising the stepwise differentiation of the processes involved, whereby the processes were divided in single macro-structural process-steps, which were further divided into activities. At last elements were assigned to the various activities. These elements are the elementary modules of the comparisons, since they allow the association of costs through well-established methods and formulas of the cost and investment calculation. It has been shown that the process approach is cost-effective.

The holistic process approach developed in this study is suitable for the built-up of hybrid structures that are locally, load-related reinforced. Especially for parts showing large differences in local load situations the approach offers best mechanicals as well as economical results.