

ENHANCING SUSTAINABILITY THROUGH THE TARGETED USE OF SYNERGY EFFECTS BETWEEN MATERIAL CONFIGURATION, PROCESS DEVELOPMENT AND LIGHTWEIGHT DESIGN AT THE EXAMPLE OF A COMPOSITE SEAT SHELL

W. Hufenbach, M. Krah, R. Kupfer, S. Rothenberg, T. Weber, P. Lucas

Technische Universität Dresden, Institute of Lightweight Engineering and Polymer Technology, 01062 Dresden, Germany; Email: ilk@ilk.mw.tu-dresden.de

Abstract Focus of this paper is the sustainable lightweight design of a composite seat shell and the development of a fully-automated high-volume production process for lightweight-optimized automotive structures made from fibre-reinforced thermoplastics. It was shown, that the lightweight component was able to meet all static and crash-relevant requirements in combination with a weight reduction of nearly 50 %. Accompanying analyses of the economical and ecological key figures pointed out that the designed lightweight seat shell can be produced at equal costs with less resource demands than the original steel part.

1 Introduction

Considering the growth rate of the global population and the therewith associated enormous increase in resource demands – resource-poor countries like Germany – are forced to explore new ways of resource usage in order to ensure their wealth. Lightweight engineering with its inherent material and energy efficiency offers the potential to combine high technological requirements with resource conservation and cost effectiveness. Thus lightweight engineering can strengthen the vision of a sustainable economical growth. Especially in the mobility industry – as a key industry of the German economy – these issues are currently highly focused.

The “Dresdner Modell” with its vision of function integrated lightweight system engineering in multi-material design has set the benchmark in the development of efficient lightweight products. By extending the constructive development methodology in respect to resource conservation, future lightweight products are developed technologically and economically sophisticated as well as resource ef-

ficient. Within the Collaborative Research Centre 639 (SFB 639) and the associated transfer unit 639 a new fibre rein-forced thermoplastic seat shell for the VW Golf plus and VW Tiguan has been developed. The development was performed at the Institute of Lightweight Engineering and Polymer Technology (ILK) and its tight linked development partner, the R&D Department of the Volkswagen AG. Within this paper the new process technology for structural interior part will be introduced and a resource orientated analyses on both parts will be performed.

2 Development of a Lightweight Seat Shell

The task for the development was to design a novel lightweight seat shell which permits the highest possible weight reduction without impairing mechanical properties and production costs. After analyzing the basic conditions the use of textile-reinforced thermo-plastic materials seems to be an appealing approach to achieve the stated requirements. Due to their good mechanical properties and short cycle times during processing, textile-reinforced thermoplastic composites gain increasing relevance for high-volume lightweight applications. Using fast-stroke presses in combination with efficient pre-heating systems, complex structural parts can be produced within a few process steps as demanded in automotive applications.

The seat shell was chosen as a reference object for the new process technology since it is a complex and well elaborated structural part, which in addition is highly stressed in case of a crash. Furthermore it was intended that the results of the development shall indicate the novel technology potential. Therefore it was necessary to conduct studies on the mechanical and economical key figures to compare the results with the already known details of conventional steel seat shells.

In view of the fact that the lightweight seat shell was developed in respect to the holistic design approach of the “Dresdner Modell” the design was not only determined by mechanical and economical aspects. In order to enhance the sustainability of the novel seat shell parallel to the engineering process a prospective resource-orientated product assessment was carried out. By the means of this approach the life cycles of the steel and lightweight seat shells were analyzed in respect to their resource demand.

3.1 The Seat Shell Development in Detail

Typically seat shells used in modern cars are made of steel. The reference part used in the 2010 VW Golf plus and Tiguan is made of one steel pipe and four spot welded plates which are all coated by cataphoretic painting. In total the mass of

the reference part is 4.6 kg. The multistage manufacturing process for this part with several forming and joining steps is time and cost intensive.

The design concept of the new lightweight shell pursued an integrated design approach by combining semi-finished textile-reinforced thermoplastic hybrids (TRTP) and long-fibre reinforced thermoplastics (LFRT)¹. The developed process technology allows to manufacture the whole lightweight seat shell within a single step. Furthermore the composite seat shell already features a stress optimized design. In particular this means that variable wall thicknesses in highly stressed load introduction areas are realized by applying additional local textile patches as well as forming complex stiffening structures out of the LFRT. In total this leads to a drastically cut of weight to 2.4 kg. The differences in structural design can be seen in Figure 1.

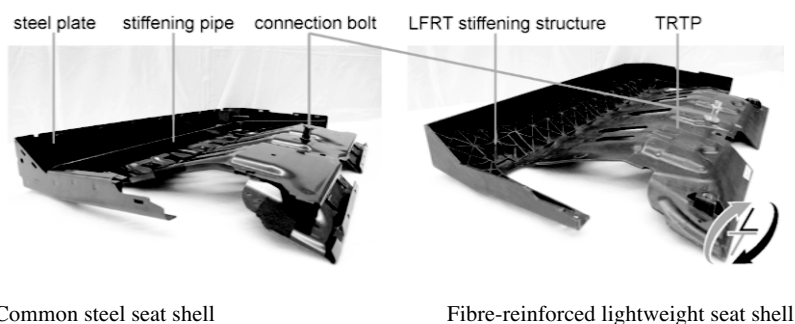


Fig. 1 Comparison of the seat shell designs.

Since the structure of the original steel part needed a stiffening pipe in order to cope with the crash requirements large efforts in terms of simulating and mechanical testing under static and highly dynamic loads were carried out to evolve a LFRT stiffening structure which guaranties a highly stressable link to the TRTP ply stack. For this purpose different semi-finished products made of thermoplastic hybrid yarns, e.g. fabrics, knitted fabrics and multiaxial multilayered fabrics were assessed in respect to their potential usability for the lightweight seat shell. [1-3] Therefore material properties were obtained which served as input parameters for LS-Dyna analyses. The comparison of simulated and tested mechanical deflections under load showed a deviation of not more than 3 %.

¹ Within the development process it was decided to use glass fibre reinforced polypropylene (GF/PP).

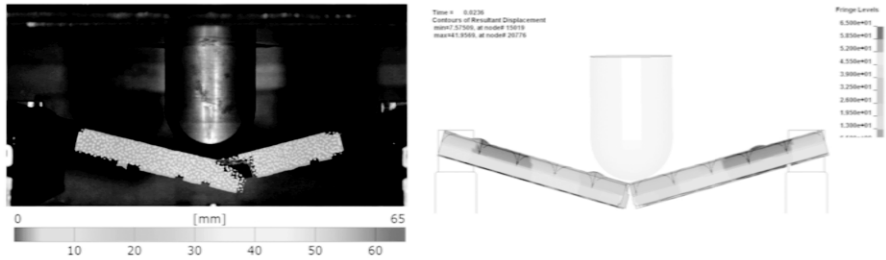


Fig. 2 Comparison of tested and simulated fibre reinforced stiffening structures in a 3 point bending crash bench.

Further failure analyses revealed the need of a surface layer made of fibre-reinforced thermoplastic fabrics to avoid unintended failure behaviour. In order to trace back influences of the manufacturing process on the fracture behaviour different failure modes were localized by the means of 3D computed tomography analysis.

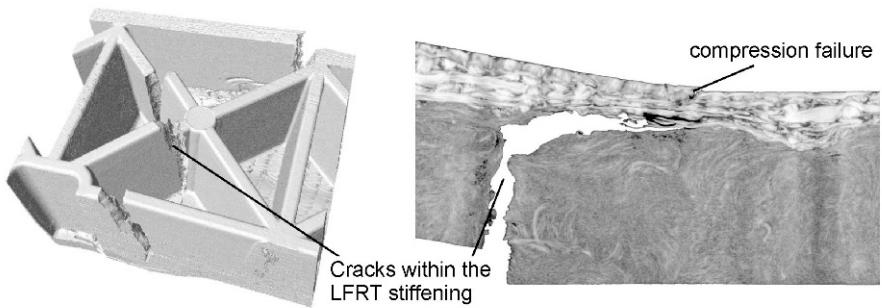


Fig. 3 Investigations on the failure modes of the stiffening structure using a CT scanner.

To establish a stable high-volume capable production process for the light-weight optimized seat shell a fully automated manufacturing process chain was designed and built. The developed process begins with the positioning of the pre-formed textile surface layer and the individual reinforcing patches. The ply stack is then heated in an infrared emitter field up to a processing temperature of 180 °C, meanwhile the LFRT-compound is extruded. By the means of a fully automated handling system, both components are simultaneously inserted into the moulding tool. For the handling system and pressing mould adapted fixing elements had been developed to prevent a slipping of the textile surface layer during the transfer and press process. The trimming of the consolidated seat shell to the final shape takes place in a subsequent stamping process. Several optimizations of the process parameters lead to an entire process time of less than 45 s.

3.2 Analyses of the Resource Efficiency of the Seat Shells

Within the “Material Efficiency and Resource Conservation” (MaRes-) Project founded by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety and the Federal Environment Agency several analyses on the resource efficiency of the novel process technology were carried out. Therefore the production chains of the steel and composite seat shell were analysed via the “Material Input per Service Unit” (MIPS-) Concept.[4] MIPS features an input orientated approach which allows to estimate the resource productivity of complex systems within a short period of time. Studies on the result quality of different abridged lifecycle oriented concepts in comparison to the life cycle analyses (LCA) showed that MIPS was able to achieve result equality. [5]

Analogous to LCA in the first step it is mandatory to determine the objectives of the analyses. In case of the seat shells the resource demand of both products with regard to the service units ‘lightweight seat shell’ (LWSS) and ‘lightweight-kilogram’ (LWKG) ought to be analysed. Under that perspective an inventory analysis was carried out. Therefore it was necessary to analyse the production processes, define realistic product life cycles, measure process times and energy consumptions for both seat shells. Table 1 gives an overview of the collected data set and the live cycle specific assumptions.

By the means of the collected data the energy and material inputs of the different life cycle phases were aggregated and multiplied with the material input factor (MI-factor). This factor represents a material intensity value for individual input materials and energy quantities (also known as “rucksack factor”). The resulting resource consumptions are related to the preliminary defined service units.

Referring to the service unit LWSS the novel composite seat shell shows higher resource preservations in every aspect of the analyses (Figure 4). It can be observed that the resource demand of the steel part is dominated by the raw material acquisition- and use-phase. In contrast the resource consumption of the lightweight seat shell is primarily influenced by the production- and use-phase. It appears that due to the higher energy demands for heating up the thermoplastics the production phase of the lightweight seat shell is more resource intensive. However within the use phase the resource demand could be traced back to the weight related fuel consumptions, hence the lightweight part passively helps to lower the CO₂ emissions.

Table 1 Overview of the assumptions for the MIPS analyses

Type of the seat shell	Life cycle phase	Energy & Materials Inputs, Assumptions
Lightweight seat shell	Raw Material	Input of Polypropylene
	Acquisition	Input of E-glass fibres
		Distinction of energy input for the production of

		LFRT & TRTP	
		30 % of the LFRT can be obtained as recycling product [6]	
Common steel seat shell	Production	Energy input via infrared emitter field	
		Energy input via extruder	
		Energy input via tool heating	
		Energy input via handling robot	
		Recycling of the stamp scrap	
	Use	Estimated lifetime 150.000 km	
		0.12 l Diesel saving through the reduction of 100 kg per 100 km [7]	
	Recycling	After the use phase it is possible to recycle the fibre reinforced thermoplastic seat shell	
Common steel seat shell	Raw Material	55 % Input via hot rolled, blast furnace steel	
	Acquisition	45 % Input via electric arc finance road steel [8]	
	Production	Energy input trough the cathodic electrophoretic coating	
		Energy input via spot welding is negligible	
	Use	Estimated lifetime 150.000 km	
		0.12 l Diesel saving through the reduction of 100 kg per 100 km [7]	
	Recycling	After the use phase it is possible to recycle the whole steel seat shell	

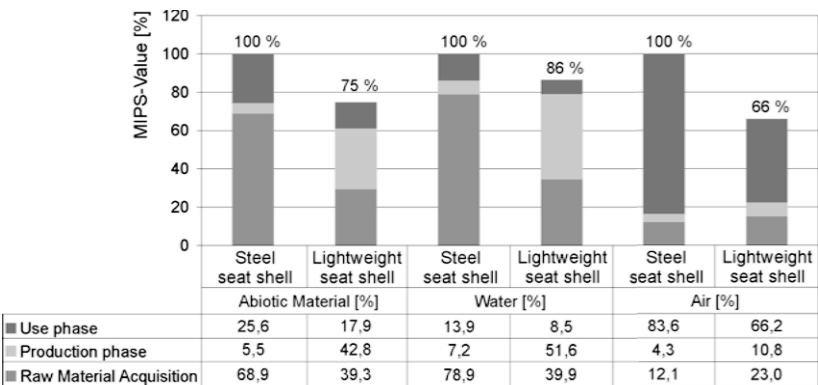


Fig. 4 Distribution of resource demands over the entire life cycle, referring to LWSS

Under the perspective of LWKG a sensitivity analyses was performed under the perspective of analysing the resource demand for 1 kg seat shell produced in the described manner (Figure 5). The analysis shows that if the seat shells would have an equal weight, the steel seat shell would be less resource demanding. Anyhow through a targeted exploitation of the mechanical properties of the fibre re-

inforced plastic it is possible to lower the weight even further than what would have been necessary for equilibrium in resource consumption.

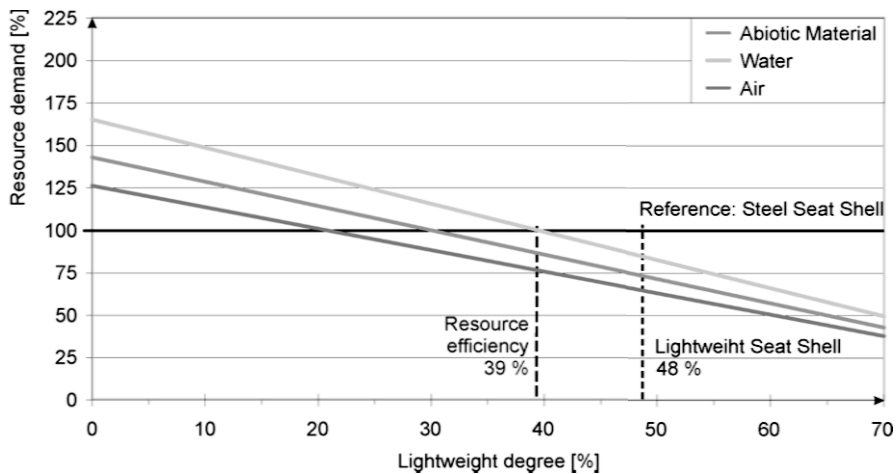


Fig. 5 Influence of the lightweight degree on the resource demand, referring to LWKG.

4 Summary

Within the frame of research of the SFB 639 and the MaResS project a novel process technology for the production of fibre-reinforced thermoplastic structural parts was developed and assessed in respect to the caused resource demand. The conducted studies on technological, economical and ecological issues acknowledge that the developed composite seat shell offers superior characteristics in respect to all aspects of the conventional steel counterpart. Although the weight of the lightweight seat shell was reduced by nearly 50 % it was shown, that the lightweight component was able to meet all static and crash-relevant requirements. Additionally it was indicated that these improvements were generated without impairing economical key figures. Furthermore a life cycle analysis regarding the resource consumptions of the seat shells was performed. For this purpose the MIPS concept with its “cradle to grave” approach was used. The results of the analysis showed that the lightweight seat shell can significantly lower the resource consumption by a range of 14 to 34 % relative to the steel part. This gives powerful arguments for the novel lightweight-design and manufacturing technique to be applied for prospective high-volume production.

Acknowledgments

The authors would like to express their gratitude towards the Deutsche Forschungsgemeinschaft (DFG) for supporting the research within the Collaborative Research Centre SFB 639 “Textile-Reinforced Composite Components in Function-Integrating Multi-Material Design for Complex Lightweight Applications.” Likewise the authors would like to express their special thanks to the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, the Federal Environment Agency and the Wuppertal Institute for supporting the research within the “Material Efficiency and Resource Conservation” Project.

References

- [1] HUFENBACH, W.; GUDE, M.; EBERT, CH.: Hybrid 3D-textile reinforced composites with tailored property profiles for crash and impact applications. *Composites Science and Technology* 69 (2009) 9, S.1422-1426.
- [2] HUFENBACH, W.; GUDE, M.; BÖHM, ET.AL.: Numerical and experimental deformation and failure analysis of 3D-textile reinforced lightweight structures under impact loads. Tagungsband 13th European Conference on Composite Materials (ECCM-13), Stockholm, 02.-05. Juni 2008.
- [3] HUFENBACH, W.: Textile Verbundbauweisen und Fertigungstechnologien für Leichtbaustrukturen des Maschinen- und Fahrzeugbaus. Progressmedia Verlag und Werbeagentur GmbH, Dresden 2007.
- [4] LETTENMEIER, M., ROHN, H., ET. AL.: Resource Productivity in 7 Steps, Wuppertal Institute, Umwelt, Energie GmbH, online: http://www.wupperinst.org/uploads/tx_wibeitrag/ws41.pdf, 2010.
- [5] ATIK, A.: Entscheidungsunterstützende Methoden für die Entwicklung umweltgerechter Produkte, Dissertation, Darmstadt, 2000.
- [6] Diebold, K.: Vom Produktabfall zum „Abfall“-Produkt, in: *Industrieanzeiger*, Ausgabe02/2010, 2010.
- [7] KOFFLER, C.; ROHDE-BRANDENBURGER, K.: On the calculation of fuel savings through lightweight design in automotive life cycle assessments. *International Journal of Life Cycle Assessments*. 2010, Nr. 1, S. 128-135.
- [8] STAHL ZENTRUM: Engagement für Stahl 2009, Düsseldorf, online: www.stahl-online.de/stahl_zentrum/Jahresbericht2009rzAnsicht.pdf, 2009.

Sustainable Automotive Technologies 2011
Proceedings of the 3rd International Conference
Hung, S.; Subic, A.; Wellnitz, J. (Eds.)
2011, IX, 144 p., Hardcover
ISBN: 978-3-642-19052-0