Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 10 (2011) 2086–2091

Engineering Procedia

ICM11

An integral design and manufacturing concept for crash resistant textile and long-fibre reinforced polypropylene structural components

W. Hufenbach[a], A. Langkamp[a], F. Adam[a], M. Krahl[a], A. Hornig[a]*, M. Zscheyge[a], K.-H. Modler[b]

[a]*Technische Universität Dresden, Institute of Lightweight Engineering and Polymer Technology (ILK), Holbeinstr. 3, 01307 Dresden, Germany*
[b]*Technische Universität Dresden, Institute of Solid Mechanics (IFKM), 01062 Dresden, Germany*

Abstract

For the design of crash resistant structures for automotive applications, mainly metallic materials are currently considered. However, the advanced specific energy absorption capacity and a high lightweight potential qualifies fiber and textile reinforced thermoplastic composites for such components. With a load adapted material design as well as an efficient manufacturing concept these properties can be exploited to a full extend.
A seat pan is chosen as an exemplary structure to illustrate the four main aspects of the investigations: evaluation of glass fiber polypropylene composite configurations; development of a manufacturing and process chain; crash and impact experiments on structural level and numerical modelling strategy.
Hybrid yarn based textiles, such as a commercially available 2/2-twill fabric and novel multi-layered flat bed weft-knitted fabrics have been considered to be combined with a long-fibre reinforced thermoplastic material (LFT, cutting length of 25 mm) for complexly loaded sections like ribbings. A special emphasis is set on a similar to mass-production manufacturing process. A fully automated integral hot pressing process has been developed, where an automated handling system places the conglomerate of extruded LFT-material and preheated hybrid yarn textile in a fast-stroke press, achieving process cycles of 45 s. Finally, the structural evaluation under crash loading conditions is compared against numerical results.

Keywords: composites; textile reinforcement; thermoplastics; series production; crash and impact; finite element analysis

* Corresponding author. Tel.: +49-351-463-38007; Fax: +49-351-463-38143 (A. Hornig).
E-mail address: Andreas.Hornig@TU-Dresden.de (A. Hornig).

 doi:10.1016/j.proeng.2011.04.345

1. Introduction

Structural components for automotive crash applications are today commonly made of metal based materials. Within the scope of lightweight engineering, fibre and textile-reinforced thermoplastic composites are getting of greater interest for industry. Especially due to their high specific energy absorption capacity and the possibility a tailored load adapted material and component design, this class of composites is predestinated to be used for structural components under crash and impact loading conditions. Thermoplastic composites offer a number of advantages compared to classical composites based on thermosetting matrices, among which the possibility for a low-cost, rapid production has to be mentioned first [1,2,3,4].

A seat pan structure for automotive applications (Fig. 1) is chosen here to demonstrate the development of an integrated design and manufacturing process, aiming mainly on weight reduction and equal or lower manufacturing costs. This includes material choice in correlation with the characterisation of according orthotropic material properties and component design, including a crash absorbing substructure. Subsequently, the development of a cost-effective manufacturing process ready for series production and the numerical modelling strategy with an experimental impact validation are presented here.

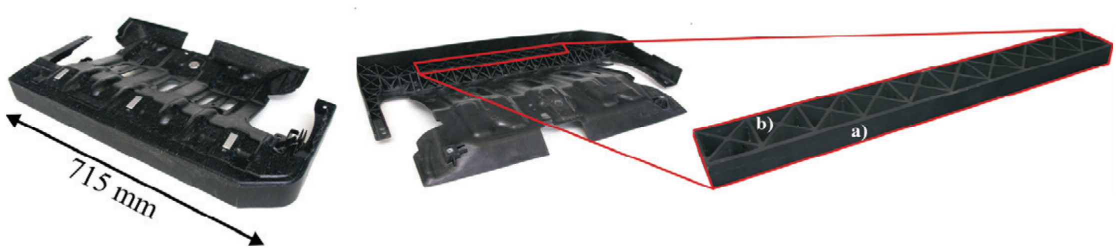

Fig. 1. Main seat pan structure (left: top view, middle: bottom view) and investigated crash absorbing substructure (right) with a) upper shell (textile reinforcement) and b) stiffening ribbing (LFT)

2. Material configurations

The main seat pan shell structure (Fig. 1) has been designed with the scope of an efficient manufacturing process on the one hand and using thermoplastic textile composite materials made of commingeled E-glass/polypropylene yarns on the other hand. The crash absorbing substructure (Fig. 1) is bears the main part of energy in case of a vehicle crash event. It consists of an upper shell made of the same material configuration as the main shell structure and a stiffening ribbing part.

For the main shell section multiple glass-polypropylene (GF/PP) hybrid yarn based textile configurations have been considered, namely a multi-layered flat bed weft-knitted fabrics (MKF), a woven fabric (Twintex®) and a non-crimp fabric (NCF). The MKF with a fibre volume fraction of 48 % is uniquely produced by the Technische Universität Dresden, Institute of Textile Machinery and High Performance Material Technology (ITM) and offers excellent draping and crash properties [5]. Twintex® TPP 60 745 is supplied by Saint Gobain-Vetrotex and is a 2/2-twill weave with a fibre volume fraction of 35 %. Selected strain rate dependent material properties are shown in Fig. 2. A comprehensive comparative characterisation and more detailed information regarding these materials and the textile architectures can be found in [6,7,8]. The NCF is supplied by P-D Glasseiden GmbH Oschatz and available with biaxial and multi-axial reinforcement.

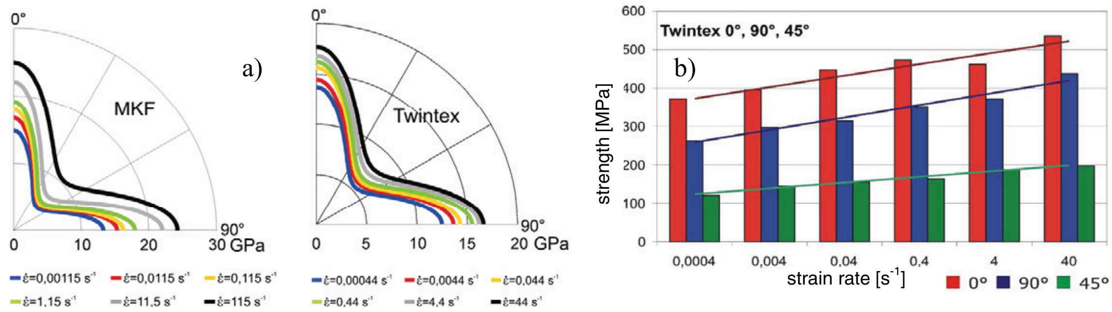

Fig. 2. Selected strain rate dependent material properties for MKF and Twintex: a) modulus of elasticity and b) strength

3. Manufacturing and Process Chain

The seat pans structural design concept (Fig. 1) combines a layered textile reinforced shell as the main part with the LFT moulding compound for the stiffening ribbing structure. Starting from the mould construction, an integral hot-pressing process for series production purposes has been developed to realise the part manufacturing. Subsequently, the interlinking the individual process steps led to the development of a fully automated production process (Fig. 3).

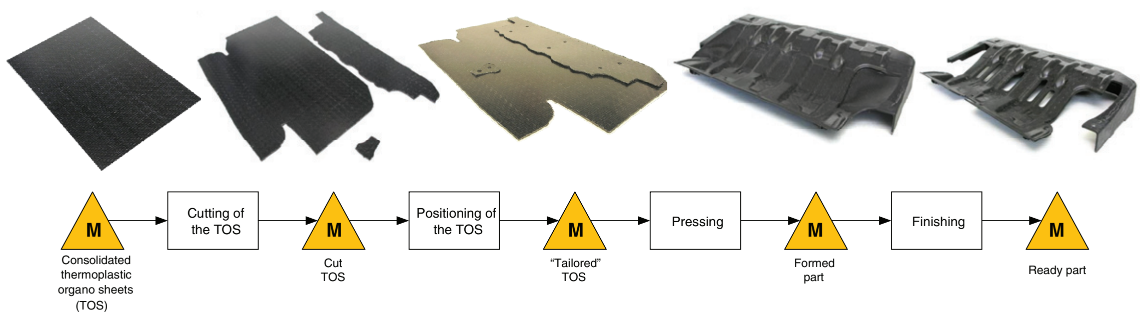

Fig. 3. Process chain of the fully automated seat pan manufacturing

Consolidated textile GF/PP thermoplastic organo sheets (TOS) are water jet cut, stacked and positioned according to the part contour. Additionally, for a better handling in the following process steps, they are fixed by ultrasonic welding. This tailored TOS is automatically positioned in an infrared radiator and heated to 180 °C. In parallel, the PP/long glass fibre pallets are processed resulting in a polymer melt (LFT) which is extruded and positioned on the heated TOS. A fully automated handling system transfers the hot TOS/LFT semi-finished compound in the fast-stroke press (max. pressing force: 30 000 kN) for the pressing and consolidation process. Fixation mechanisms in mould are used, avoiding dislocations of the single textile layers during the pressing. The cycle time for one seat pan equals 45 s. The development and optimisation of this process was supported by computer tomographic, ultrasonic and thermographic non destructive evaluations (NDE) and static and dynamic experimental investigations. Especially the LFT-textile GF/PP bonding configuration could be significantly improved (Fig. 4).

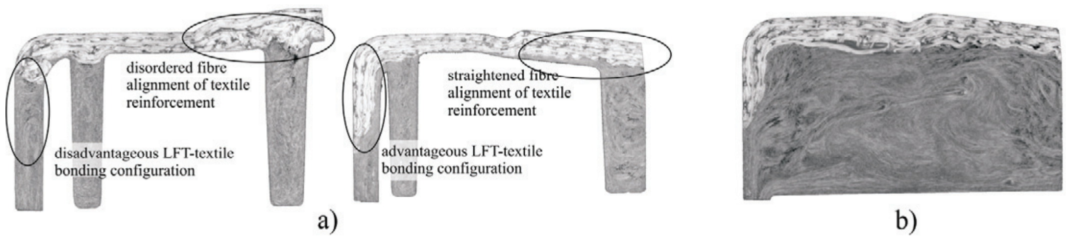

Fig. 4. NDE of manufacturing quality by computer tomography: a) comparison of initial (left) and optimised (right) LFT-textile GF/PP bonding configuration; b) exemplary short fibre orientation and fibre clustering due to the manufacturing process

4. Crash and Impact Experiments

The crash absorbing substructure (Fig. 1) with its LFT ribbing geometry in combination with the GF/PP textile reinforcement layers have been investigated in detail regarding their crash and impact performance. The results of these experiments were used for the calibration and validation of the numerical strategy and evaluation of material configurations. The 3-point-impact-bending (3PIB) test setup is illustrated in Fig. 6 a) with the corresponding FE-Model. The specimens were cut out of seat pans manufactured within the developed manufacturing process (Fig. 3). In total four material configurations LFT-MKF, LFT-Twintex, LFT-NCF and LFT-LFT have been impacted with 33.6 J. A high speed digital image correlation system (ARAMIS®) and two high velocity cameras were used to capture the strain and deformation fields.

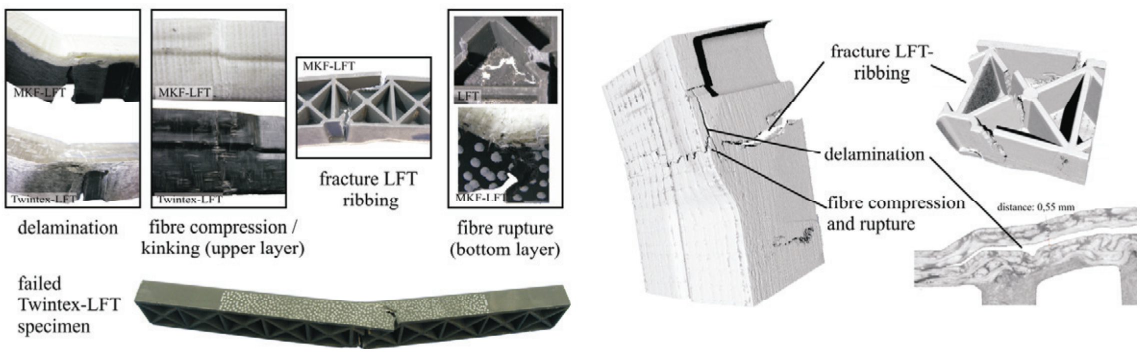

Fig. 5. Failure modes due to 3-point-impact-bending: visual (left) and CT (right) analysis

The failure modes delamination and fibre rupture and compression/kinking, which are typical for textile reinforced composites, can be observed as a result of the impact bending experiments (Fig. 5). Due to the optimised LFT-textile GF/PP bonding configurations, inter-material delaminations have been prevented. The material configuration LFT-LFT without any textile reinforcement showed the worst resistance performance in terms of maximal deflections and energy absorption. This underlines the necessity of continuous fibre reinforcements.

The main seat pan structure is a part of the rear seat assembly. Besides the two static loads of misusage conditions of either right or left sided punctual 100 kg loading at the front edge, crash loads have to be considered: a front crash with a vehicle velocity of 56 km/h and three persons on the rear seats (each 80 kg) and with child safety seats (ISOFIX system). The final structural design (Fig. 1) fulfilled both static and highly dynamic loading case requirements on a full scale car crash testing rig. In the static experiments no damage was detected. Only minor and noncritical damage occurred in the upper shell of the crash absorbing substructure and hair-line cracks in the ribbing structure.

5. Numerical modelling

Both the main seat pan structure and the crash absorbing substructure have been subject of extensive and successful static and dynamic numerical investigations. With the calibration and verification of the modeling strategy based on the substructure impact experiments, the main structure's structural behaviour has been realistically predicted. Due to the neglectable failure and damage occurrence in the main structure, the focus is set here on the impact modelling of the 3PIB experiments of the substructure (Fig. 6 a), using the explicit FE- solver of LS DYNA 971. For the textile reinforced GF/PP material the material model MAT 54 (ENHANCED_COMP_DAMAGE) was used, allowing using fracture mode based failure criterions based on Chang-Chang. The LFT material is modelled using MAT 24 (PIECEWISE_LINEAR_PLASTICITY). The strain rate dependent material behaviour was considered by adapting the material properties to the occurring strain rates. Thus, the impact failure behaviour could be predicted as illustrated in Fig. 6 b).

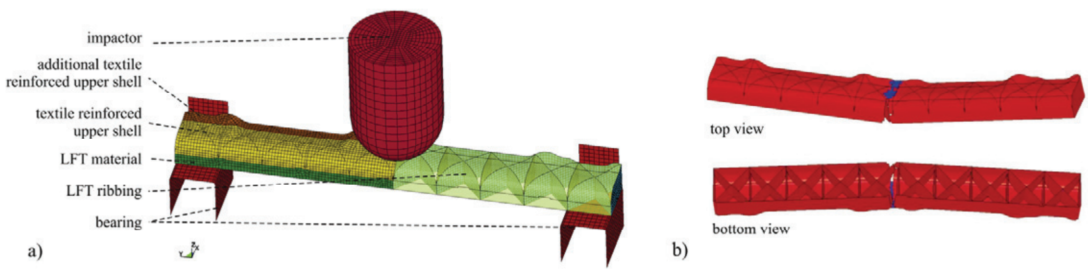

Fig. 6. a) 3-point-impact-bending test setup and FE-modell for the crash absorbing substructure and b) results of the numerical impact analysis: fibre compression failure (top) and fibre rupture (bottom)

Besides the damage and failure prediction, the structural impact response was calculated. As the direct comparison with the experimental results show (Fig. 7), a very good chronological correlation of the impact phases has been achieved: initial contact (0 ms), ending elastic deformation - failure initiation (3.6 ms), maximal deflections of 30 mm (19.8 ms), 40 mm (23.6 ms) and 60 mm (38.4 ms).

6. Conclusions

A seat pan structure for automotive applications made of textile and long fibre reinforced thermoplastic composite material has been designed under consideration of static and highly dynamic crash and impact boundary conditions. Based on extensive material characterisation and manufacturing studies, an integral manufacturing process for economical serial production purposes has been developed. The design process was supported by explicit numerical calculations to predict the components crash and impact behaviour. The results have been verified within experiments on component and substructural level. It could be shown, that a weight reduction of 2 kg compared to the steel part can be achieved at equal manufacturing costs.

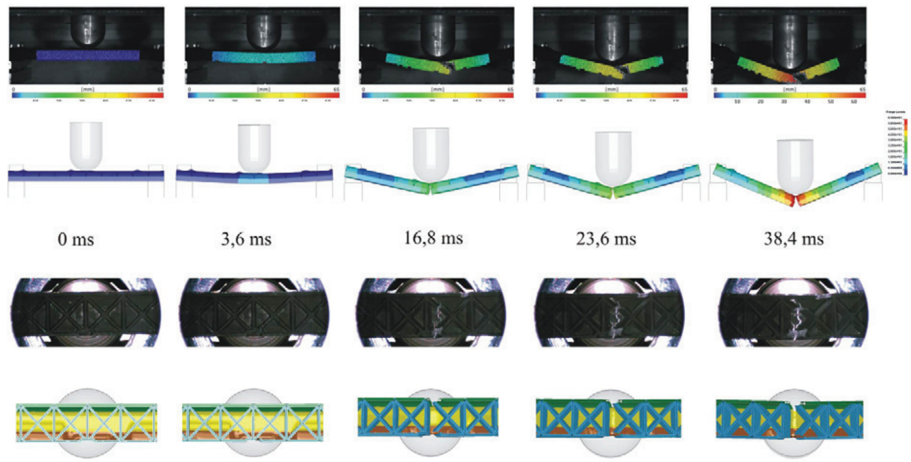

Fig. 7. Comparison of experimental and numerical results of the 3PIB experiments: top - absolute displacement (side view); bottom - damage progress (back view)

Acknowledgements

The authors gratefully acknowledge the financial support of this research by the Deutsche Forschungsgemeinschaft (DFG) within the Collaborative Research Centre (SFB) 639 “Textile-reinforced composites for function-integrating hybrid construction projects in complex lightweight applications”, subproject C4 and Transfer Project T7.

References

[1] Hufenbach W, Adam F, Beyer J, Zichner M, Krahl M, Lin S, et al. Development of an adapted process technology for complex thermoplastic lightweight structures based on hybrid yarns. In: *ICCM 1)*, Edinburgh, July 27–31; 2009.

[2] Schade M, Diestel O, Cherif Ch, Krahl M, Hufenbach W, Franeck J, et al. Development and technological realization of complex shaped textile-reinforced thermoplastic composites. In: *Composites in automotive and aerospace* (5th international congress on composites), Munich, October 14–15; 2009.

[3] Long A C, Wilks C E and Rudd C D. Experimental characterisation of the consolidation of a commingled glass/polypropylene composite, *Compos Sci Technol* 61 (2001), pp. 1591–1603.

[4] Tufail M. Processing investigation and optimization for hybrid thermoplastic composites, *J University Sci Technol Beijing* 14 (2007), pp. 185–189.

[5] Cherif C, Rödel H, Hoffmann G, Diestel O, Herzberg C and Paul C *et al.* Textile manufacturing technologies for hybrid based complex preform structures, *J Plast Technol* 6 (2009), pp. 103–129

[6] Hufenbach W, Böhm R, Thieme M, Winkler A, Mäder E, Rausch J, Schade M. Polypropylene/glass fibre 3D-textile reinforced composites for automotive applications. *Materials and Design* 32 (2011), pp. 1468–1476

[7]Hufenbach W, Gude M, Ebert C, Zscheyge M, Hornig A. Strain rate dependent lowvelocity impact response of layerwise 3D-reinforced composite structures, *International Journal of Impact Engineering* (2011), doi:10.1016/j.ijimpeng.2010.12.004

[8] Brown K A, Brooks R, Warrior N A. The static and high strain rate behaviour of a commingled E-glass/polypropylene woven fabric composite, *Compos Sci Technol* 7 (2010), pp. 272 - 283