

SEATING STRUCTURES AND OTHER STRUCTURAL APPLICATIONS WITH LOCALLY UNIDIRECTIONAL REINFORCED THERMOPLASTIC COMPOSITES

A. Rüegg, R. Ayer, D. Jaggi, Esoro AG, Switzerland
N. Stötzner, Albert Weber GmbH, Germany

Abstract

A new mass production process combining unidirectional continuous (endless) and long fiber thermoplastic (E-LFT) allows the production of highly loaded structural components. This one-shot production process is a combination of the well-established LFT process and a new process for unidirectional continuous fibers, which enables low cost mass production of complex structural lightweight parts. The continuous unidirectional fiber tapes (EF) provide excellent mechanical characteristics and can be inserted three-dimensionally following exactly the paths of load. Serial production will start by the end of 2006.

The advantages of E-LFT components and the process are:

- **High performance:** E-LFT parts have very high mechanical properties and can therefore replace structures, which have been dominated by metallic solutions.
- **Lightweight:** Weight reductions between 30 and 45% compared to metallic solutions have been proved.
- **Cost efficient production:** Fully automated production process, low cost base materials, short cycle times
- **Integration potential:** The process offers high integration potential.
- **Recycling:** The components are fully recyclable.
- **Short cycle times:** Cycle times between 30-60sec are possible, thanks to the thermoplastic matrix and the highly automated production.

This paper sets the focus on the application field of E-LFT components, especially pointing out seating structures. Different studies of structural components, implicit and explicit (crash simulation) finite element calculations with validation in a sled-test-front-crash with luggage retention are shown. The advantages over the current solutions and the trend of locally reinforced components will be displayed.

Introduction

Parts made from long-fiber reinforced thermoplastics (LFT) are nowadays the first choice for large semi-structural components of automotive applications. Technical reasons are the persuasive characteristics of the components, particularly with regard to weight, functional integration and energy-absorption. Very efficient production processes like LFT-D-ILC (direct impregnation) [1] are the economic reasons. The compression molding process allows to fabricate large parts in very short cycle times and with very little fiber damage.

To enhance the performance of such parts, local reinforcements are now widely discussed [2], [3], [4]. The reinforcements consist of metal-inlays [3] or continuous fiber reinforced thermoplastics, like tapes (continuous filaments) or woven-fabrics [2], [4]. Such reinforcement can improve the mechanical part performance enormously.

On behalf of **Albert Weber GmbH**, ESORO AG has already developed and patented the proprietary **E-LFT** process from the original idea in 1998 through concept trials to a fully-automated pilot line. A specific pilot plant station with its additional testing facilities was set up. Parallel to this, the necessary fundamentals for E-LFT component engineering have been developed. Having all process and design specialists in-house enables very efficient component engineering. Serial production with a first part starts by the end of 2006.

E-LFT process

E-LFT stands for continuous (**Endless**) fiber reinforced **Long Fiber Thermoplastic**. It combines the well established LFT compression molding process with the local inlay of unidirectional continuous fiber tapes (EF).

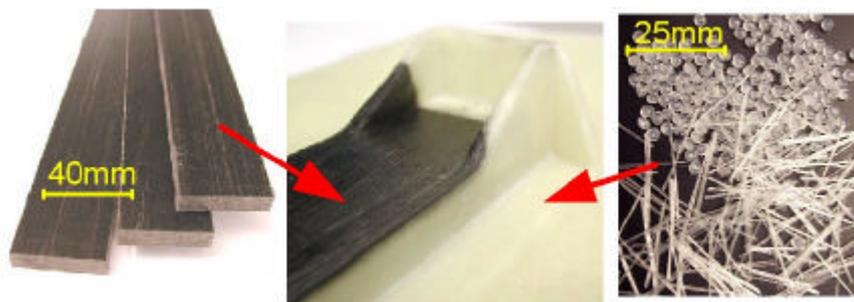


Figure 1: Base-materials EF(left) & LFT(right) with E-LFT part-section (middle)

The E-LFT process is designed for fully automated production. The principal components are EF processing, LFT processing, handling (robot) and press, see figure 2. The EF processing and the handling system for this process are completely new developments. As is the case with LFT processing, a frame press with parallel mechanism is also used in the E-LFT process.

As figure 2 shows, LFT and EF are processed parallelly and placed together into the mold by a handling-system. The semifinished EF sticks are heated in an infrared field while the LFT is processed with an extruder. The two elements EF and LFT have to be compression-molded in the molten state, otherwise no good bonding between the materials will result. An efficient handling places the materials in one shot at the exact position. When the press closes and fills the cavities of the mold, the bonding between EF and LFT is realized. Standard compression molds can be used and because of the vertical flash faces and the exact dimensions and placement of the EF strips no edge trim is necessary.

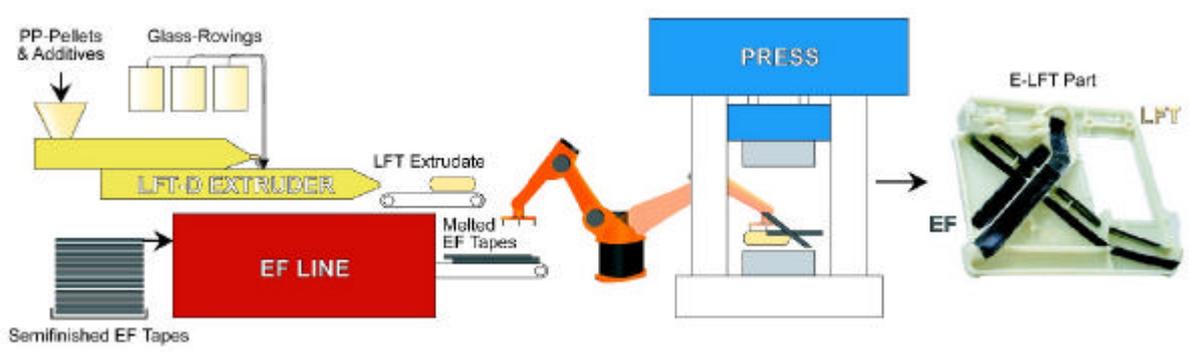


Figure 2: E-LFT setup layout

EF and LFT mainly consist of the same materials, generally polypropylene and glass fibers. However, it is also possible to process other fibers (carbon or aramide) and matrices (PET, PBT, PA and ABS) [2]. LFT consists usually of 30% of weight glass fibers (PPGF30) and EF has a higher content of as much as 60% of weight (PPGF60). In this paper all published data are of said fiber contents.

E-LFT component characteristics

Combining LFT and EF allows the component properties to be enhanced in targeted manner. Enhancement of several hundred percent in the mechanical characteristics is possible by comparison with pure LFT components, see figure 3. The strength and rigidity values of the EF tapes are exceedingly higher than those of LFT (figure 3). The EF tapes can be placed in almost any shape according to the load paths and the component geometry – see figure 4. Different three-dimensionally shaped EF tapes with various cross-sections can be realized in an E-LFT part. So the component can be reinforced with the minimal amount of reinforcement, resulting in an immense light-weight potential.

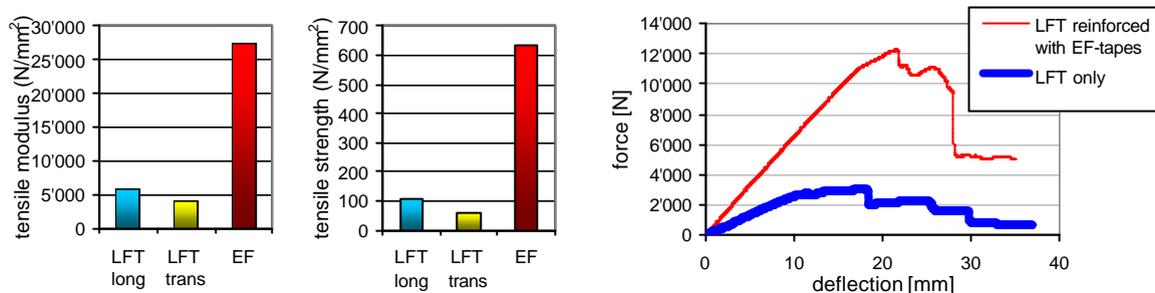


Figure 3: (left) Mechanical properties of base-materials
(right) Mechanical properties (3 point bending) of an E-LFT component compared to an LFT part

Component advantages [5]:

- High stiffness and strength: Especially because of excellent EF properties.
- Nearly temperature independent material properties because of EF tapes with high fiber content and unidirectional orientation.
- Excellent crash properties: Impact properties of E-LFT components are several times higher than the already good properties of pure LFT parts.
- Good creep resistance: EF framework, which has very low creep.
- Design freedom: Excellent design freedom of LFT and 3-D insertable EF tapes.
- Light weight: Specific reinforcement and low density materials (LFT 1.12g/cm³, EF 1.48g/cm³)
- Resistant against dynamic loads because of good EF-LFT interface properties.
- Integration potential: Easily more functions can be integrated compared to metal parts.
- Reproducible component properties: Exact placement of EF tapes and optimal process control, which is very important for safety component production.



Figure 4: Possibilities of EF tape design freedom, EF is colored black, LFT natural

Seating structures and other structural applications

The E-LFT process is designed for high volume production of large components, which have high structural loads and where light-weight, high integration potential and cost efficiency are important requests. Therefore seating structures are, among others, target parts. In the following different seating studies are displayed.

2/3 Rear seatback (with integrated seatbelt joint)

The target was to substitute a metal seatback of a medium sized car (figure 5) and to outline the performance and benefits of the composite solution. The E-LFT seatback is therefore a 1:1 substitution with the same fixation points so it could be tested accordingly to the metal seatback. Further requirements were: weight reduction, same stiffness, meet crash requirements.



Figure 5: (left) metal seatback, (middle) E-LFT seatback, (right) middle seatbelt joint

The seatback is fixed on the bottom on both sides (pivoted) and at the top on the left side (lock), see figure 5 left. The middle belt is fixed in the center on top, where the long EF tape ends. Head rest joints are also integrated. The big opening on the left side of the part is for the ski-load-through. The highest applied loads result in a front crash situation, where the part has to withstand the middle belt force and the luggage forces. The component contains four EF-strips (colored black in figure 5 middle), which connect the main load joints. The EF inlays with their high mechanical properties are designed in complex 3-D geometry, cross each other and build a framework, unlike any other mass production process known.

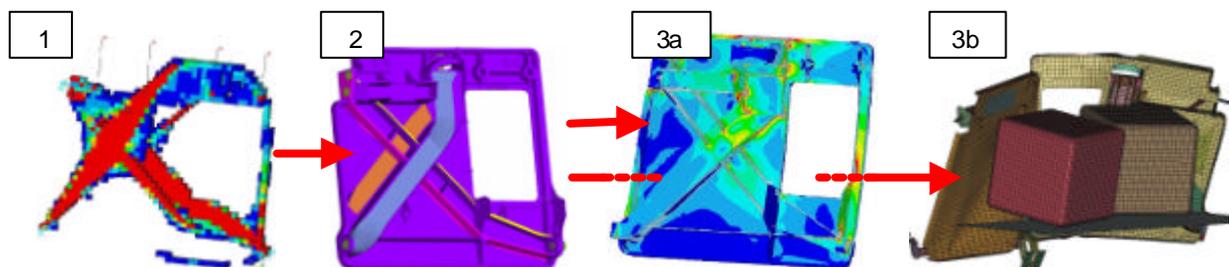


Figure 6: Simulation path: 1. topology optimization, 2. design, 3a. implicit FEM (Ansys), 3b. explicit FEM crash simulation (LS Dyna)

To realise fast engineering cycles and good correlations between simulation and reality, several simulation techniques are used. Especially with complex structure topology optimization gives first hints where to place the reinforcements. Additionally process know-how is very important to realize a good and feasible design. Depending on load types, different FEM

simulations are carried out. For static loads implicit FEM analysis (Ansys) and in case of crash loads explicit FEM analysis (LS Dyna) are used (figure 6).

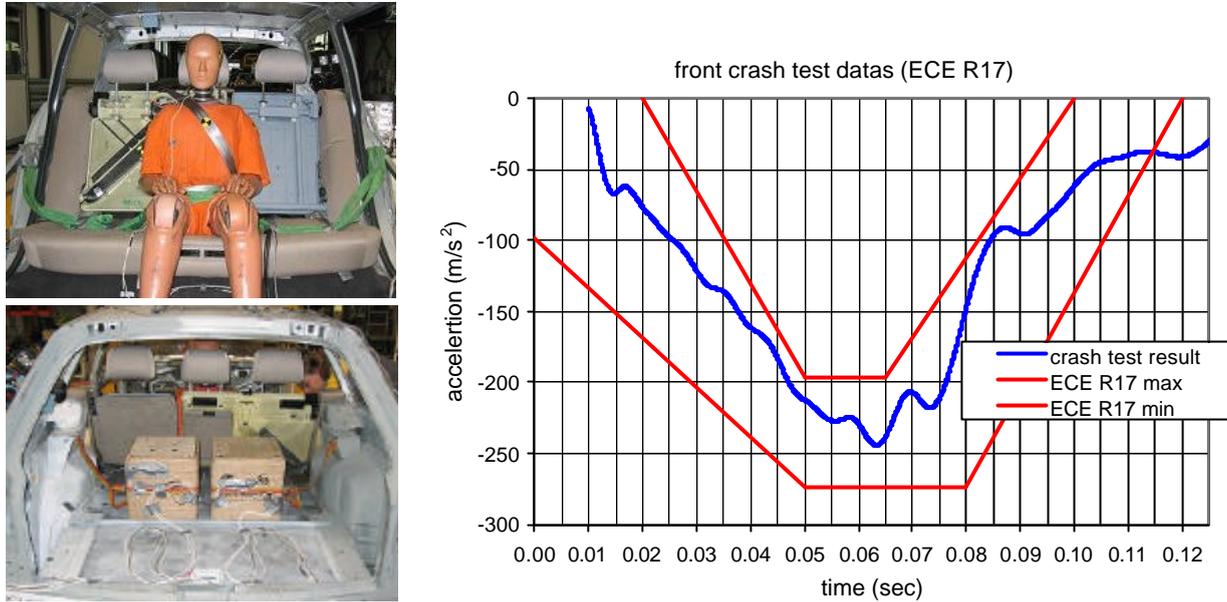


Figure 7: Front crash test ECE R17 + dummy (full-width frontal crash, $v=50\text{km/h}$, $a_{\text{max}}=28g$, 50% male hybrid III dummy, 2 cubes (18kg each), sled test with hydrobrake): (left) pictures of test setup from front and back with dummy, (right) measured crash pulse data

Different tests were carried out to verify the simulation results and to give proof of the feasibility of the composite structure. All tests were passed, even the most stringent front crash test, see figure 7 and table I. The comparison of simulation and test results showed very good correlation, which proves the reliability of the simulation.

Table I: Results of the 2/3 rear seatback study

Requirements and results		
Very high weight reduction	<input checked="" type="checkbox"/>	47% less than metal
Stiffness equal to metal version	<input checked="" type="checkbox"/>	94% of metal version
Head rest test (pendulum) SAE J921	<input checked="" type="checkbox"/>	
Belt force test (tensile): ECE R14	<input checked="" type="checkbox"/>	
Front crash test: ECE R17 + dummy (full-width frontal crash, $v=50\text{km/h}$, $a_{\text{max}}=28g$, 50% male hybrid III dummy, 2 cubes (18kg each), sled test with hydrobrake)	<input checked="" type="checkbox"/>	Very good correlation to simulation results

The E-LFT solution achieved a very high weight reduction (**-47%!**) and fulfilled all other requirements. Because of further integration potential and the momentarily boundary conditions specified for a metal part, even a higher performance can be realized. The costs are competitive to the metal solution.

Rear seat system of a compact car

In this study a rear seat system for a small sized car had to be carried out. The main targets were: light weight, modularity and crash performance. The seatbacks have to be able to flip down, to gain more room for the trunk. The system is divided in two 50% seats (left and right), which are symmetrical. The different load joints of the right and left seatback are solved just with other EF (local reinforcements) placement. Therefore the same tools can be used for the left and right 50% seat.

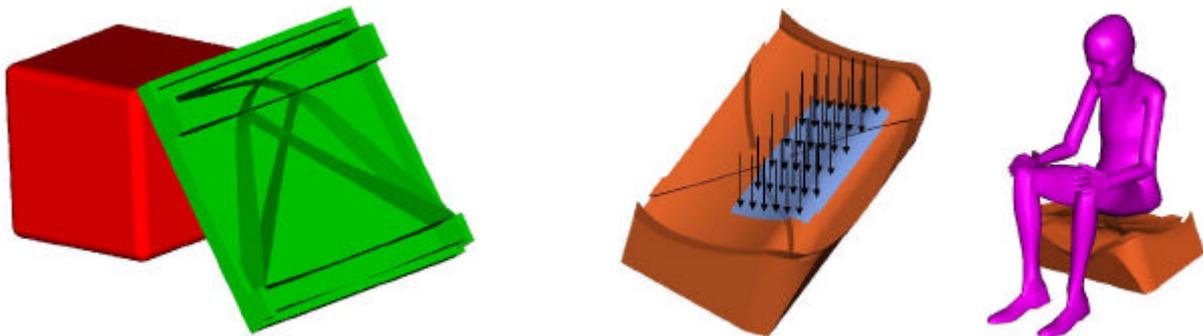


Figure 8: (left) seatback and luggage retention cube, (right) seat pan and seat pan with dummy

For the seatback highest loads result from a front crash situation, where the seatback has to withstand the luggage retention. In case of the seat pan it is the weight of the person. The requirements and forces are listed in table II.

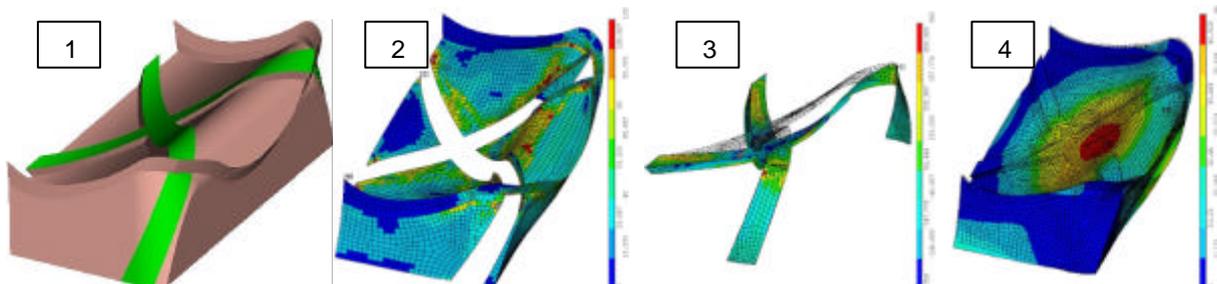


Figure 9: 50% Seat pan: 1: CAD design with EF reinforcement colored green
2.: Von Mises stress of LFT section (0 to 120 N/mm²), 3: Longitudinal stress of EF section (-350 to 560 N/mm²) 4: Deformation of E-LFT seat pan (0 to 46mm)

The E-LFT seat pan weighs 2.5kg and measures 550x320x360mm. In figure 9 it can be seen where the local reinforcements (green) are placed. The circular flange is used for the fixation of the cover. The FEM pictures show stress and deformation results. Figure 9/2 shows the von Mises stress of the isotropic LFT section, while figure 9/3 shows the longitudinal compression and tensile stresses of EF tapes.

In figure 10 the CAD design of the 50% seatback is shown with the EF reinforcement colored blue. The EF tapes are placed for the right 50% seatback in the ribs like the drawing shows and for the left seatback they are placed symmetrically in the other ribs. So the same tool for both seatbacks can be used. The backside of the component is flat and therefore usable for trunk extension. The circular flange of the seat pan is used for cover fixation. In total the E-LFT part weighs 2.85 kg and measures 510x450x60mm.

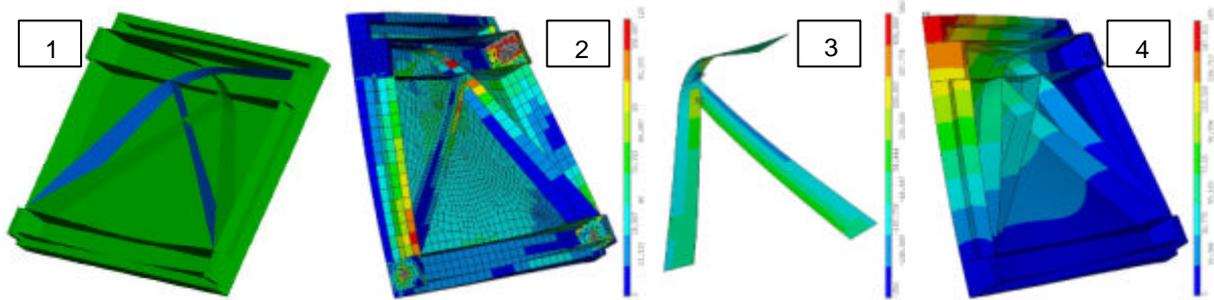


Figure 10: 50% Seatback: 1: CAD design with EF reinforcement colored blue
 2: Von Mises stress of LFT section (0 to 120 N/mm²), 3: Longitudinal stress of EF section (-350 to 560 N/mm²) 4: Deformation of E-LFT seat pan (0 to 165mm)

The FEM results show, that the components withstand the applied loads. The materials are used very efficiently, which results in a very light structure, see table III. If the belt system is added (1.5kg each), the complete seat system has the very low weight of 24.2kg. With minimal tool equipment (only two tools), low cost materials and an efficient production process a very good price value results for this rear seat system.

Table II: Forces and Requirements

Forces and requirements		
50% Seatback		
	Loading	18 kg
	Resulting force	10.6 kN
50% Seat pan		
	Weight of dummy	78 kg
	Resulting force	30 kN

Table III: Calculated weight of the rear seat system

	50% Seat pan	50% Seatback
E-LFT structure	2.5 kg	2.85 kg
Carpet	---	0.5 kg
Foam	1.0 kg	1.0 kg
Cover	0.45 kg	0.45 kg
Headrest	----	0.7 kg
Fittings	0.5 kg	0.5 kg
Total	4.45 kg	6.0 kg

Lightweight driver seat

This study shows a new structural E-LFT concept for a composite driver seat with integrated belt joint. The lightweight driver seat is designed for sport and lightweight vehicles.

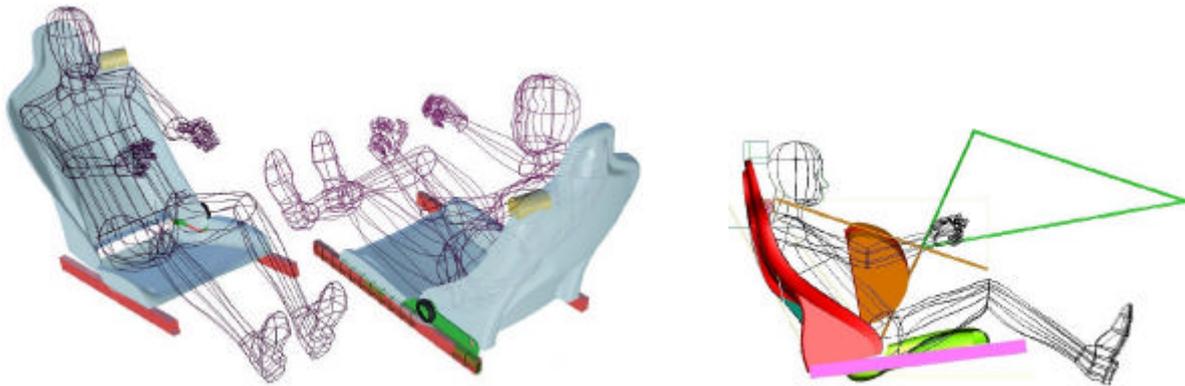


Figure 11: Lightweight driver seat

The seat does consist of a seatback and a seat pan. The seatback has an adjustment system integrated, to vary the angle of the seatback. Both parts are mounted on a sled-system for longitudinal adjustment and fixation to the carbody. A big part of the surface is visible and carried out as a textured surface. The component geometry is designed as a body-contoured seat to fit optimally to the body of the driver.

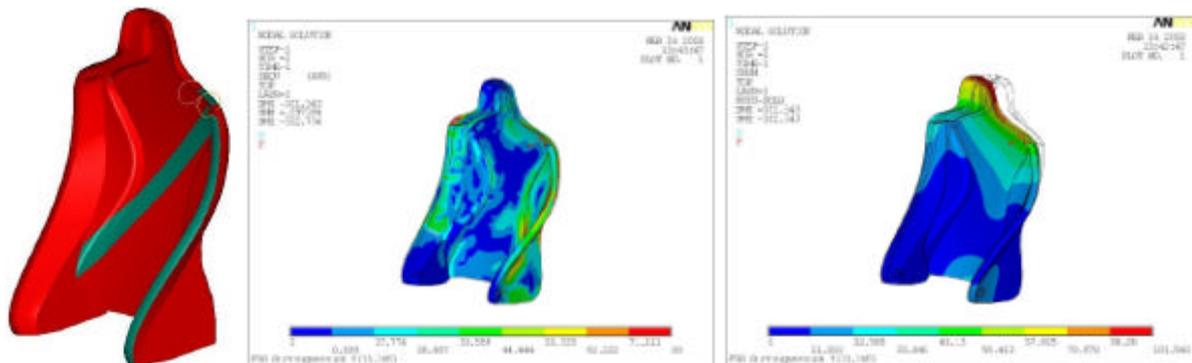


Figure 12: Seatback: (left) CAD design with EF reinforcement colored black (middle) von Mises stress (0 to 80 N/mm²), (right) deformation data of E-LFT seatback (0 to 101.5mm)

Because of the high loads of the belt joint in a front crash, the seatback has to be reinforced with unidirectional EF tapes. In figure 12 the EF reinforcements, which lead to the belt joint, are colored in black. The FEM data show good results and the OEM specifications could be achieved. The E-LFT parts weigh only 5.3kg and the complete seat is estimated with 18kg.

Table IV: Results and advantages of the lightweight driver seat

Result and advantages	
Weight of E-LFT components (seat pan & seatback)	5.3 kg
Weight of complete seat	18 kg
Seat belt joint included in E-LFT structure	✓
OEM specifications achieved	✓

20% Rear seatback module

The 20% rear seatback module is not a very large part but has high load applications, high integration potential and is therefore an excellent E-LFT part. While the steel part has to be covered completely, the E-LFT component can be implemented with a textured surface on the backside to avoid an additional cover part.

In figure 13 the original steel part and the complete module is displayed on the left and the E-LFT component design on the right. The E-LFT 20% rear seatback is carried out with four EF strips, which are aligned with an offset to the neutral axis to gain maximal performance, see figure 13 on the right. The E-LFT process allows to place the EF-tapes exactly at the required places and with the necessary specific cross-section. Like this, real light weight structures are possible.



Figure 13: Rear seatback module : (left) steel version and complete module, (right) E-LFT part with cross section

Because of the front crash requirements the 20% rear seatback has to withstand top and bottom luggage retention, which are very stringent requests for a composite component. FEM results showed, that the OEM specification can be achieved and a very high weight reduction of 40% can be realized. If the design-space was more flexible, more functions could be integrated into the E-LFT part, instead of only replacing the metal part with a 1:1 substitution.

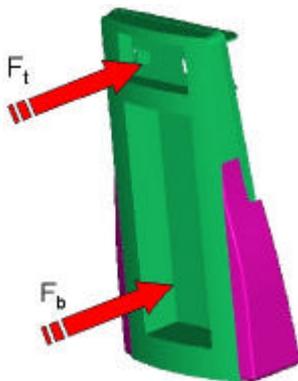


Figure 14: Loads applied in a front crash

Table V: Front crash requirements for a rear seatback module

Front crash requirements	
Velocity	56 km/h
Mass of top luggage	20 kg
Mass of bottom luggage	2 x 18 kg

Table VI: Results and advantages of the rear seatback module

Result and advantages	
Weight reduction	40%
OEM specifications achieved (front- and rear crash)	<input checked="" type="checkbox"/>
Integration potential: texture-surface, cup holder	<input checked="" type="checkbox"/>

Conclusion & E-LFT target components

The single-stage E-LFT process which is suitable for large-scale production results in low-cost components entirely without material offcuts which, thanks to the targeted combination of EF and LFT, feature a performance spectrum exceeding that of conventional LFT or GMT parts by far. It allows applications which have been, up to the present, the sole domain of metallic components.

Especially seating structures can be carried out with very good performance and a lot of benefit to current solutions. But also other structural components are perfectly suited to be produced with the new E-LFT process, like shown in figure 15.

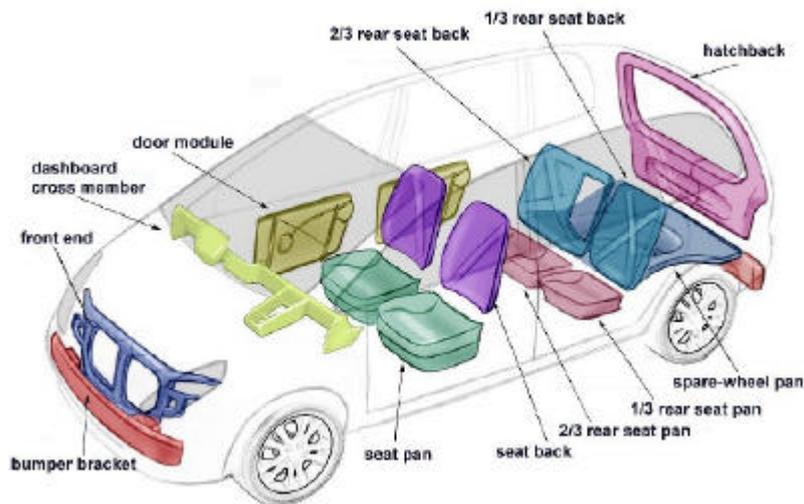


Figure 15: Automotive target components for E-LFT process

References

- [1] Henning F., Krause W., Ernst H., Brüssel, R., "LFT-D-ILC Innovative Process Technology Decreases the Cost of Large-Scale Production of Long-Fiber-Reinforced Thermoplastic Components", ANTEC, San Francisco, (2002)
- [2] Geiger O., Droeste A., Eyer P., Henning F., Krause W., "Tailored and Advanced LFT – New fields of application for LFT-D-ILC technology – Locally reinforced components made of engineering plastics", AVK-TV conference, Baden Baden, Germany, (2002)
- [3] Zoellner O.J., "Plastic-Metal Hybrid – A new development in the injection molding technology", ANTEC, San Francisco, (2002)
- [4] Hüsler D., Jaggi D., Ziegler S., Rüegg A., Stötzner N., "Direct (one-shot) compression moulding technology for mass production of structural long-fiber thermoplastic parts, using integrated structures of unidirectional fiber reinforcement", AVK-TV conference, Baden Baden, Germany, (2002)
- [5] Rüegg A., Stötzner N., Jaggi D., Ziegler S., "A new mass production process for lightweight structural parts and their application field", ANTEC, Chicago, (2005)