FIBER COMPOSITE INTENSIVE VIRTUAL URBAN VEHICLE STRUCTURE

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Abstract

A design approach is presented applying an innovative method for supporting the development of a complete future urban vehicle structure made of fiber composite material down to component level.

Based on a vehicle concept for urban transport, various FEM optimizations are carried out in order to construct appropriately to most-ideal loading paths and the use of fiber reinforced polymers (FRP). The optimization routines (including topology, free-size and size) are applied to volumes, surfaces and combinations thereof under static loads, including isotropic and anisotropic material models. As an example the optimization results of the vehicle floor and tunnel structure are presented.

1. Introduction

Due to the strict goal to reduce CO_2 emissions to 95g CO_2/km, which is specified for the year 2020 [1], there is a keen demand for lighter and lightweight designed automotive structures, as an effective way to fulfill these requirements.

A potential approach to realize this is the selective and intensified usage of fiber reinforced polymer materials (FRP). This opens further capabilities for innovative vehicle concepts with integrated property and safety functions. The challenge here is the development of a strategy within the disciplines simulation (FEM) and construction (CAD) to gain efficient and functional interactions.

In terms of FRP-structures, this means to dimension and design the fiber orientation according to the most-ideal loading paths to achieve an advantage from FRP-materials, in particular when using carbon as valuable fiber material.

In view of a holistic approach and also to prospectively meet the requirements of the automotive sector additional aspects have to be considered. Economic and production-orientated aspects, as well as joining technologies, within the scope of multi-material design (MMD), have to be considered to realize a great leap towards medium to large-scale productions.

In this contribution a top-down approach for a virtual development (strategy, method, and design together with simulation) of an FRP-intense vehicle structure with an electric powertrain for application in future urban areas is presented. A load-specific and FRP-specific optimized structural design under static load cases (bending, torsion, cornering and deceleration) is virtually generated and evaluated.

2. Methodology

2.1 Specifications of an future urban vehicle

The first challenge is to outline a geometric concept for a future urban vehicle, which is based on requirements that are obtained through market analysis and benchmark-vehicles [2]. The ergonomic arrangement of occupants in the passenger compartment and the positioning of the drive components lead to a variable parametric CAD model. In our study the package is composed of a seating configuration of 2 + 2, including space for baggage, resulting in an overall length of 3600 mm with the total mass not exceeding 1000 kg. The batteries are located in the floor structure. The chassis configuration contains a novel steerable front wheel system including electric powertrain and suspension [3]. The rear axle consists of a wheel-guided transverse leaf spring made of fiberglass composite [4].

2.2 The FRP-design approach

Anisotropic fiber composite materials offer a fundamental different behavior compared to (conventional) metallic materials, hence to use them efficiently it is necessary to adapt the specific advantages of the anisotropic character early in the design process.

In this contribution an approach is presented for an innovative usage of suitable methods on an overall vehicle level, aiming at a derivation of an optimized design proposal for the general construction method and structural discretization. An overview on fundamental steps of the proposed approach is displayed in Figure 1, showing the different development levels of the structural concept and the individual optimization methods being applied at respective stages.

Starting from the basic vehicle and geometrical concept, a parametric CAD model is created consisting of mainly surfaces covering the maximum design space of the measure concept and package. From package restrictions of the components and passengers the main body structure of the passenger compartment is tied to be located in the vicinity of the vehicle’s outer skin. Therefore most of the possible load paths of the body structure are sufficiently represented by surfaces. Design spaces, where the spatial arrangement of possible structural load paths is not yet determined, are modeled with solid volumes. In the given example these areas are located at the front and rear end of the vehicle body containing the load application zones of the suspension fastenings.

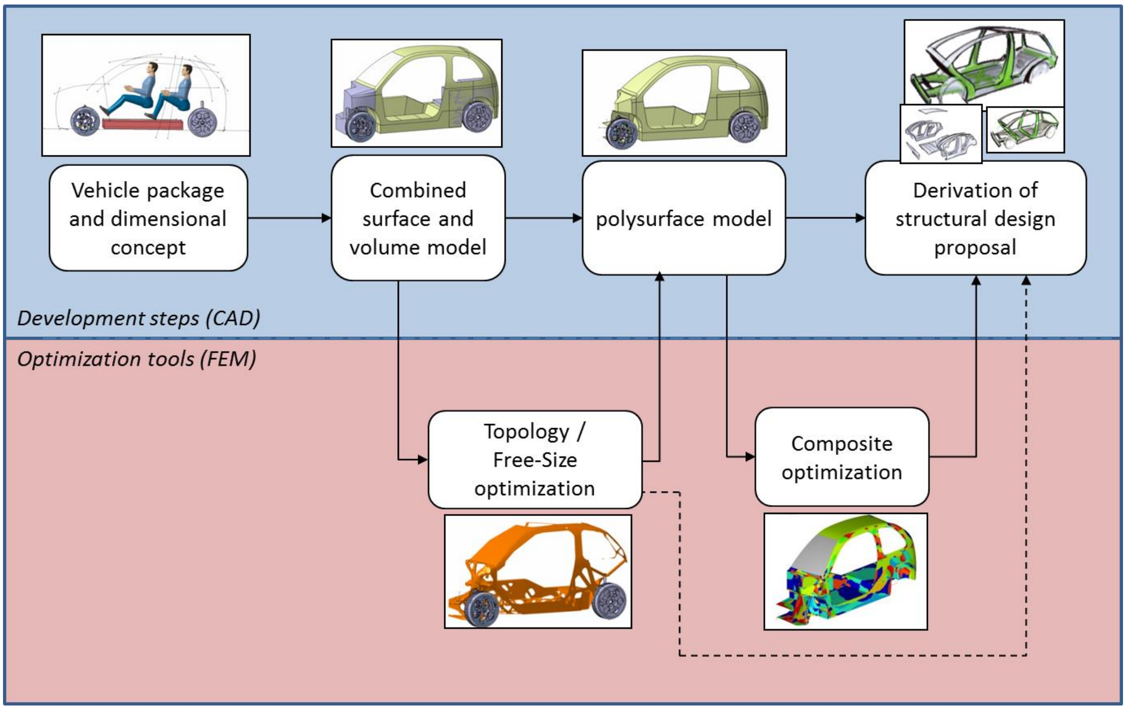


Figure 1: Method of the design approach for a FRP-intensive urban vehicle structure.

On the combined surface and volume model the first optimization routine (topology optimization) is applied in order to identify a suitable load transfer from the wheels to the passenger compartment regarding relevant load cases. By the identification of simplified surfaces from the preceded results a polysurface model is generated. This polysurface covers possible load paths for the selected load cases without being discretized into individual structural components.

With the created polysurface model the composite optimization functionality of *Altairs Optistruct®* can be utilized. The toolset can be applied serving two separate objectives, both useful in the presented development process:

1. In general, the algorithm produces a distribution of previously defined plies of a composite material. By defining discrete fiber orientations for each ply, an optimized positioning of individual fiber orientations is allocated to the polysurface. Areas with high thicknesses of a distinctive fiber angle are identified as possible discrete components with high potential for optimization. Hereby the composite optimization of the polysurface on an overall vehicle level can assist in the discretization into structural modules and thereby gives a preference for the construction method of the overall body concept.

2. Besides the fiber layers an additional sandwich core layer can be defined. By running the composite optimization with a defined core material, areas of high bending stresses are able to be identified. The algorithm increases the core thickness in regions where high second moment of area is beneficial and thus the laminate layers need to be placed at a distance. As a result, these particular optimizations are beneficial to evaluate advantageous domains for the application of sandwich constructions.

In order to decide for a particular construction method and discretization of the design space model into separate structural components, the present method offers three assisting tools for deriving a reasonable design proposal.

First, the combined volume and surface optimization reveal weight-optimal load paths for specified load cases. Second, from the composite optimization, areas of highly anisotropic stresses can be identified and separated into single modules, which offer a high potential for further fiber optimizations on a component level.

Third, the introduction of a core material in the composite optimization provides indications on areas, where a sandwich construction can be considered in the vehicle body concept.

3. Composite Optimization

3.1 Optimization setup

Four simulations are presented: Free-size and size optimization of the complete body, each with and without balsa wood as core material. They are part of the Altair optimization approach [5] in performing a composite optimization.

The optimization problem is setup to use a 130 kg mass constraint of the design space while minimizing the weighted compliance. A minimum laminate thickness of 1 mm is used as well as a minimum member size of 100 mm, because less filigree structure is easier to interpret. The manufacture thickness of one ply is defined to 0.125 mm to perform a discrete size optimization. An additional constraint is added in the size optimization to meet design requirements: the Hoffmann failure index [6] should be less than 1.

3.2 Model definition

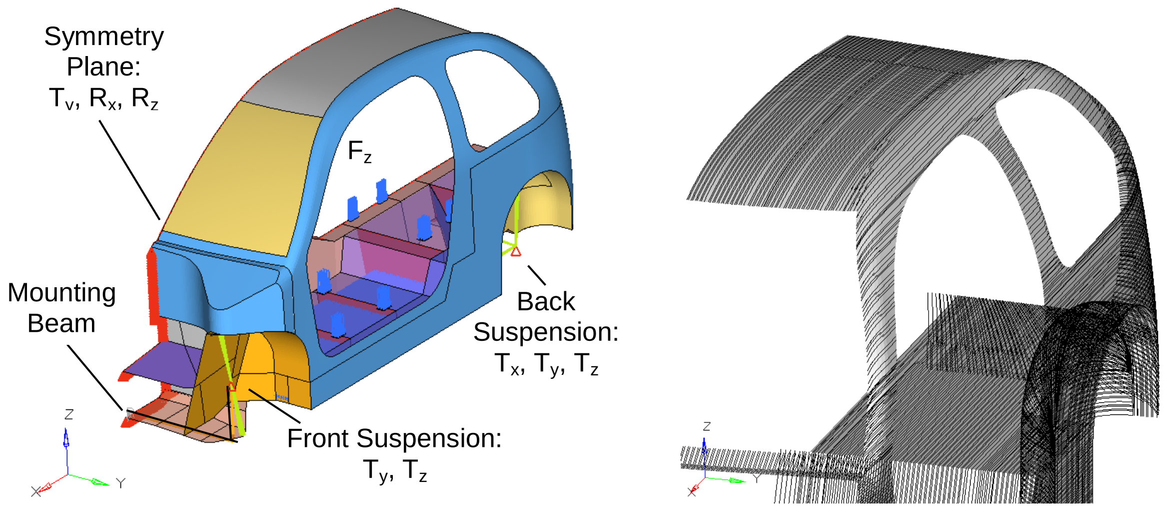
The used load cases are bending, torsion, braking and cornering, see Table 1. They are weighted for the total compliance. The total compliance is composed of the four load cases torsion (40 %), bending (40 %), breaking (10 %) and cornering (10 %).

The loading is introduced as pressure load to the seat supporters and under floor (battery weight).

Load Cases:	**Bending**	**Torsion**	**Braking**	**Cornering**
Symmetry Plane	T_y, R_x, R_z	T_x, T_z, R_y	T_y, R_x, R_z	T_x, T_z, R_y
Front Suspension	T_y, T_z	-	T_x, T_y, T_z	T_y, T_z
Back Suspension	T_x, T_y, T_z	T_x, T_y, T_z	T_x, T_y, T_z	T_x, T_y, T_z
Resultant Force at Seat Supporters	F_z= -250 N	-	F_x= 250 N	F_y= 250 N
Resultant Battery Force at Under Floor	Fz= -1250 N	-	F_x= 1250 N	F_y= 1250 N
Moment at Front Mounting Beam	-	M_x= 1500 Nm	-	-

Table 1. Overview on loading and boundary conditions (T- translation, R- rotation, F- force, M- moment)

The symmetrical half of the model for the composite optimization is shown in Figure 2a). At symmetry plane of the vehicle, symmetry and anti-symmetry boundary conditions are defined for different load cases, respectively. The suspensions are realized by using RBE2 elements. For the torsion load case, a mounting beam is used to transfer the moment from one end at the symmetry plane to the front suspension.



a) Loading and boundary condition (e.g. bending)

b) 0 degree material element orientation

Figure 2. Simulation setup.

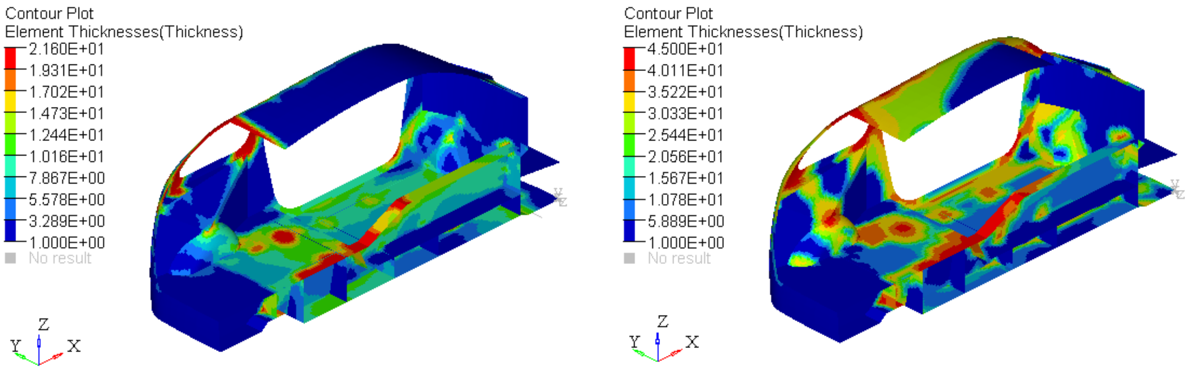
Balsa wood as sandwich core material is modelled isotropically. The material properties are shown in Table 2. The 0 degree direction is oriented parallel to the X-axis, see Figure 2b). The allowable stresses are used to calculate the composite Hoffmann failure theory index [6]. The laminate build-up for the whole car body, except the windscreen (made of glass), is (0/ ±22.5/ ±45/ ±67.5/ 90). An increment of 22.5 degree is chosen to obtain a more detailed fiber orientation compared to the commonly used 45 degree. The sandwich model uses the same laminate plus a balsa wood core thickness of max. 25 mm. For an easier post-processing the core has an orientation of 170 degree. All plies possess the same thickness, defined in such a way that the initial body mass is 3.3 times the aim mass of 130 kg, which corresponds to a mass fraction of 0.3.

Material ***Definition***	**Balsa Wood** [7] *Isotropic*	**CFRP (CF-HT fiber 60% - EP)** [8] *Orthotropic*	**Glass** *Isotropic*
Parameters	$E = 2100$ MPa $\nu = 0.3$ $\rho = 9.6e\text{-}8$ kg/mm³	$E_1 = 140000$ MPa $E_2 = 8800$ MPa $G_{12} = 4600$ MPa $\nu = 0.29$ $\rho = 1.6e\text{-}6$ kg/mm³	$E = 70000$ MPa $\nu = 0.3$ $\rho = 2.5e\text{-}06$kg/mm³
Allowable Stresses	$\sigma_T = 7.4$ MPa $\sigma_C = 6.3$ MPa $\tau = 1.8$ MPa	$\sigma_{T1} = 1670$ MPa $\sigma_{C1} = 1050$ MPa $\sigma_{T2} = 30$ MPa $\sigma_{C2} = 165$ MPa $\sigma_{12} = 80$ MPa	

Table 2. Material parameters. (EP– epoxy resin, CF-HT- high tenacity carbon fiber)

3.3 Optimization results

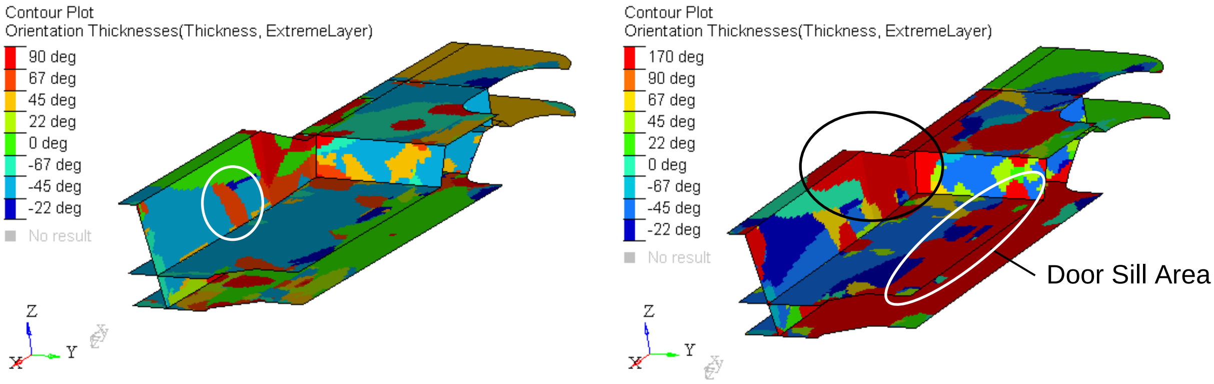
The element thickness contour plot of the free-size optimization, displayed in Figure 3, shows load concentrations (red areas) at the tunnel as well as at the B- and C pillar for both models. In the core model a thickened roof can be observed, which differs from the model without core.



a) Without core *b) With core*

Figure 3. Free-size optimized element thickness distribution.

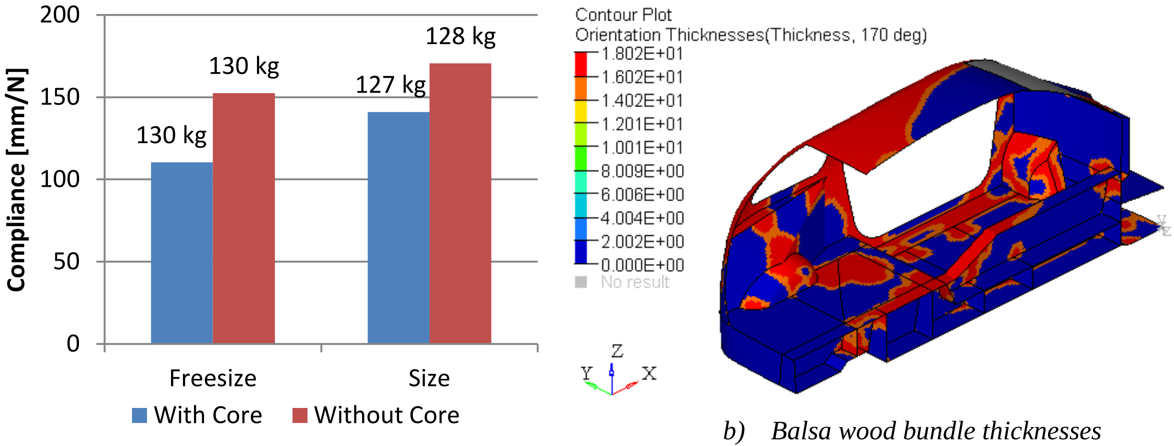
As an example for the optimized fiber orientation, the floor and tunnel structure is chosen. In Figure 4a) the top of the tunnel und the bottom floor is dominated by the 0 degree fiber layer, resulting from the bending load case. There is a 90 degree layer on the marked tunnel because the load from the front seat supporters is transferred to the top of the tunnel. The top floor has a dominant -45 degree orientation due to torsion. In Figure 4b) the bottom floor, door sill and marked tunnel area is dominated by the core. In these positions the increased second moment of area is beneficial, especially for the bending load case.



a) Without core *b) With core*

Figure 4. Design interpretation of the size optimization for the tunnel and floor structure.

The total compliance can be seen in Figure 5a). The model with core performed better than without, because the sandwich structure is used at defined areas. OptiStruct® creates four ply bundles for each orientation. In order to get a reasonable output for the core distribution, the first ply bundle covering the entire vehicle polysurface is not considered in the size optimization. Only two bundles of the core (170 degrees) are visible in Figure 5b) since one bundle is reduced to zero thickness. The maximal core thickness of 25 mm is reduced to 18 mm (red areas). The compliance from free-size to size is increased for both models because of the creation of simplified ply bundles and the additional composite failure criteria.



a) Compliance comparison

b) Balsa wood bundle thicknesses

Figure 5. Results of the composite optimization.

4. Summary and Outlook

A method for the development of a structural design for a vehicle body structure was presented, which considers the anisotropic character of fiber reinforced materials. Particular FE-algorithms (composite free-size and size) support the design process by offering insight on advantageous load paths and placement of certain fiber orientations as well as the local usage of sandwich constructions within a polysurface model. The composite optimization was performed on the complete vehicle body and exemplarily shown for a vehicle floor and a tunnel structure. The load cases applied in the demonstrated method were limited to static loads aiming at a stiff passenger compartment.

Upcoming steps will focus on the realization of components and modules based on the presented optimization results. After deriving discrete modules from the polysurface model, dynamic behavior of structural units will be studied at a detailed level.
Furthermore aspects like a crash management concept, manufacturing processes of components, joining and assembly concepts have to be taken into account, preferably also from an economic point of view, to meet the requirements of the automobile industry.

Abbreviations

CAD	computer-aided design
CAE	computer-aided engineering
CFRP	carbon fiber reinforced plastic
CO_2	carbon dioxide
FEM	finite element method
FRP	fiber reinforced polymer
RBE2	rigid body element, type two

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