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It is possible to increase the performance of fibre-reinforced composites in rail vehicles!

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Abstract

This paper describes the methodological approach to develop lightweight composite-intensive roof structure of a railroad car body from the creation of a generic car body through topology optimization to the manufacturing of a roof segment in FRP. This approach would be pursued as part of the joint project "Significant mass savings through structurally supporting fiber composite-intensive rail vehicle body structures with integrated damage diagnosis system" (faWaSiS), which is funded by the German Federal Ministry for Economic Affairs and Energy.

Keywords: fibre-reinforced plastics, FRP, topology optimisation, free-size optimisation, sandwich construction, roof structure, railway car bodies

1 Introduction

In the context of the mobility shift and the targeted reduction of CO2 emissions, new electrified drive concepts for rail vehicles, such as battery-electric or fuel cell concepts, are required. They are primarily intended to replace fossil fuels on non-electrified routes. Due to the higher mass of the new drive technologies, it is often difficult to comply with the specified axle loads. In order not to exceed the permissible wheelset loads, significant mass savings are necessary through a holistic lightweight design approach, which also includes the use of innovative materials such as fibre-reinforced plastics (FRP). The use of damage diagnosis systems (structural health monitoring, SHM) can additionally monitor highly stressed areas of the FRP and reduce the inspection effort.

Within the scope of the joint project "faWaSiS" (Significant mass saving through structurally supporting fibre composite-intensive car body structures of rail vehicles with an integrated damage diagnosis system) funded by the Federal Ministry for Economic Affairs and Energy, such an approach is being pursued and demonstrated on two selected structures (a side skirt and a roof structure). The consortium accompanied by the project sponsor TÜV Rheinland consists of the following partners: J.M. Voith SE & Co. KG (lead partner), Forster System-Montage-Technik GmbH, SAERTEX GmbH & Co. KG, EAST-4D Carbon Technology GmbH, INVENT GmbH and the German Aerospace Center e.V. (DLR).

2 Methods

The roof structure of railway car bodies - a large homogeneous surface with few cut-outs - is particularly suitable for the use of FRP. An existing systematic approach ([3], [4]) was used and further developed for the fibre composite roof concept aimed for in the project, which was optimised as far as possible in terms of force flow (Figure 1). The individual areas of the systematic approach are discussed in more detail below.

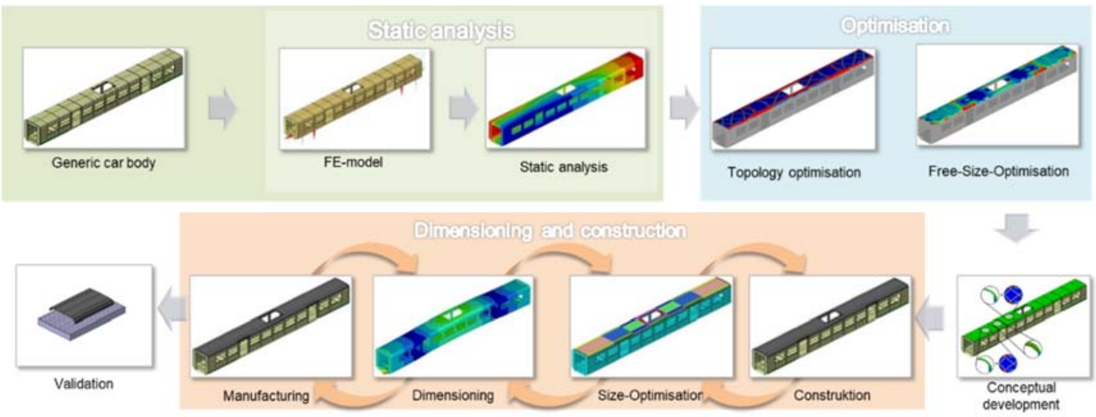

Figure 1: Systematic approach to the development of an roof structure in FRP

Using a 26.4 m long and 2.8 m wide generic car body (gen. CB) of a regional vehicle in steel differential construction and subject to the loads from DIN 12663 Part 1 2010 [1], a topology optimisation as well as a free-size optimisation of the roof area were carried out. The characteristics of both optimisations are shown in Figure 2.

The concept for the roof structure is based on a sandwich construction with a constant thickness over the entire length of the roof made of carbon-fibre-reinforced plastic (CFRP) layers and a PET foam core and longitudinal stiffeners in the transition area of the roof to the side wall. Bent sheet metal parts are to be used as connection profiles [5].

Initial calculations showed that a constant thickness of the sandwich structure of 65 mm is necessary for the required deflection, as well as reinforcement profiles above the door cut-outs in the form of hollow chamber profiles [4].

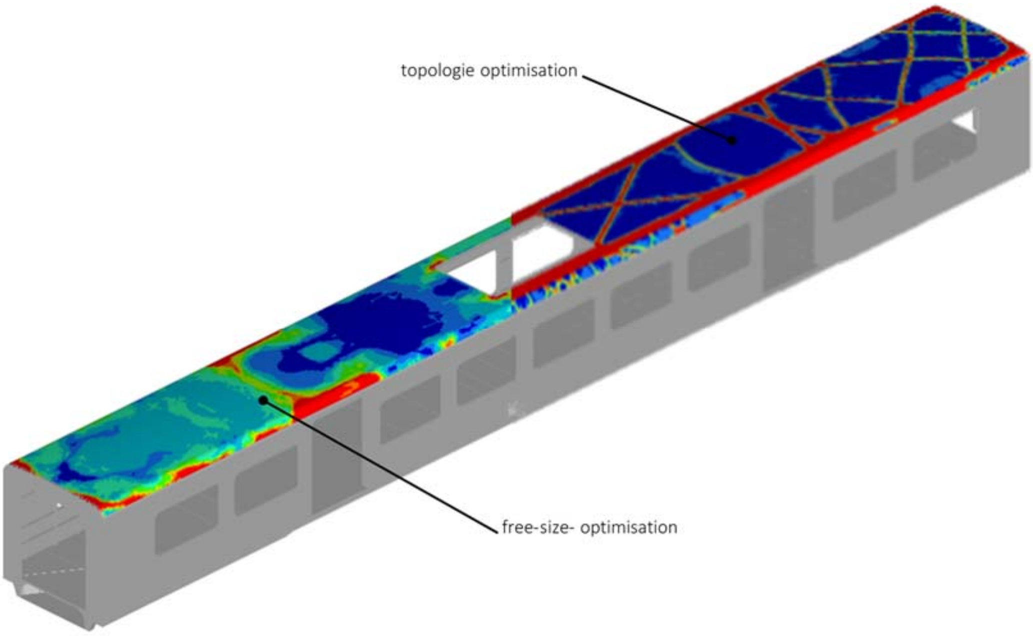

Figure 2: Selected roof area of the gen. CB with the results of the topology and free-size optimisation

For a further increase in performance, the layer structure was adapted to local and global loads and their required stiffnesses. This was done with the help of a size optimisation, in which the thickness of each individual layer within the laminate was optimised according to the occurring loads.

In the vehicle x-direction, the roof structure is divided into five individual segments. These segments have three areas in the lateral direction (y-direction), which were subdivided as follows: the two longitudinal stiffening areas (areas 1 and 3) and the ceiling area (area 2). Furthermore, the longitudinal stiffening areas were subdivided into two zones on the outside in order to do justice to the local as well as global loads, see Figure 3.

3 Results

Thanks to the systematic approach, it was possible to reduce the system mass of the roof assembly to approximately 1350 kg for both production processes. The system mass includes the masses of the sandwich structure, the lightning protection, the fire protection gelcoat and the connection elements. The individual components with the corresponding masses are listed in Figure 4. The system mass corresponds to a mass saving of 30% compared to the reference roof, whereby the system mass (structure plus insulation) of the reference roof is 1920 kg.

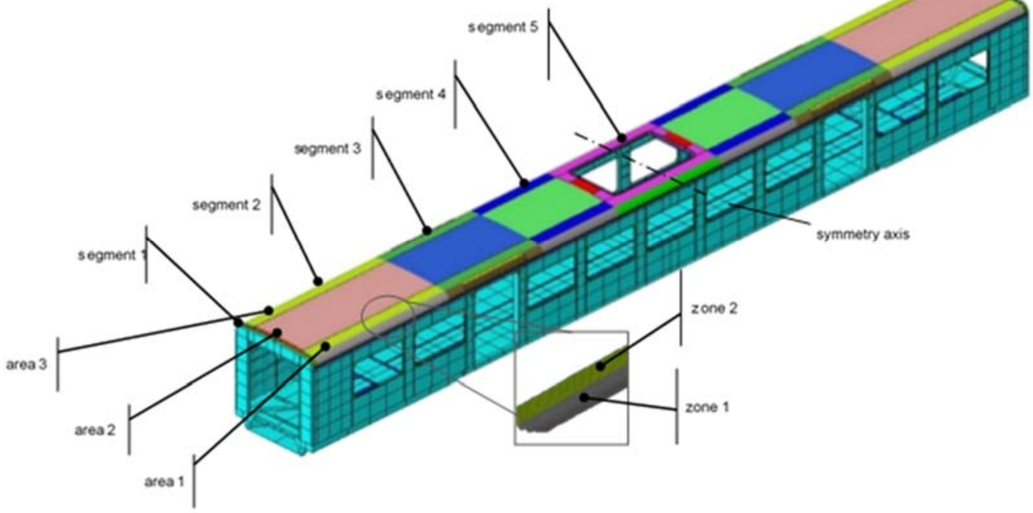

Figure 3: Conceptualisation of the symmetrical roof structure with five segments, each divided into three areas and 2 stiffening zones.

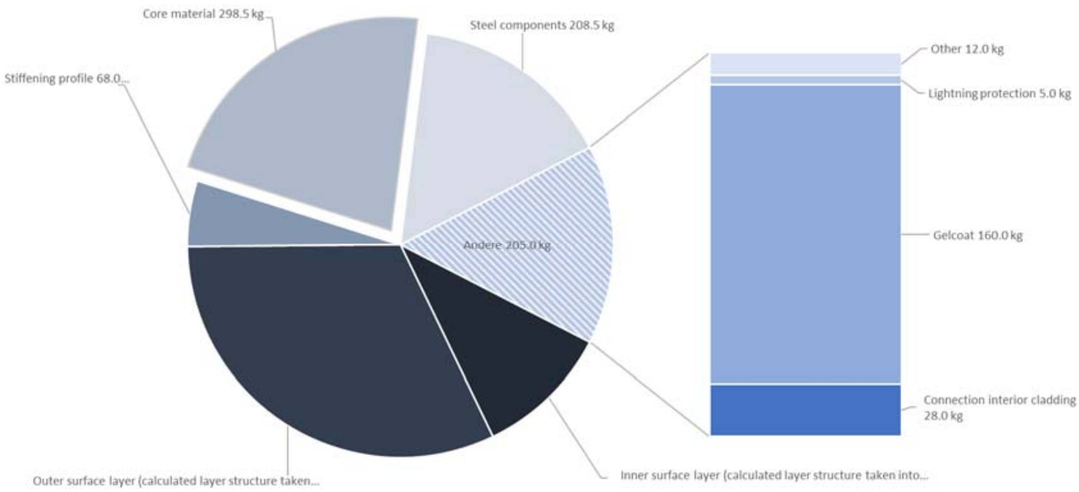

Figure 4: Masses of the roof assembly according to the simulation

Table 1 shows the computationally derived improved values of the optimised roof structure based on the manufacturing restrictions of the vacuum-assisted resin injection method (VARI) compared to the reference roof.

The validation of the roof structure in the faWaSiS project includes the comparison of masses and the quasi-static testing of a roof section manufactured using the VARI method on a scale of 1:1, with the dimensions 2.8 x 4 m. The roof segments, manufactured using the VARI process, show a significantly higher mass than predicted in the simulation. In percentage terms, the mass increase for the selected roof section is approximately 25% compared to the simulation values. Investigations of the manufactured roof structure show that the main reason for the mass increase is an unexpectedly high resin absorption of the foam core, which could not previously be taken into account in the simulation. The increased resin absorption led to an increase in the density of the foam core of around 75%.

	Gen. CB	Gen. CB + faWaSiS-roof	Deviation [%]
1g (entire vehicle) [mm]	-18.80	-18.24	-3.0
1g (roof) [mm]	-16.65	-16.09	-3.4
Lift (total vehicle) [mm]	-43.50	-45.15	3.8
1st vertical bending natural frequency [Hz]	12.51	13.20	5.1
1st natural frequency of warping [Hz]	12.89	13.95	8.2

Table 1: Comparison of the deflections and natural frequencies of the gen. CB and of the gen. CB with the faWaSiS roof (based on VARI manufacturing restrictions)

Figure 5 lists the individual components of the entire roof assembly with the associated masses after adjusting the core density. The resulting mass of the roof assembly is consequently 1576 kg. This corresponds to a mass saving of about 18%.

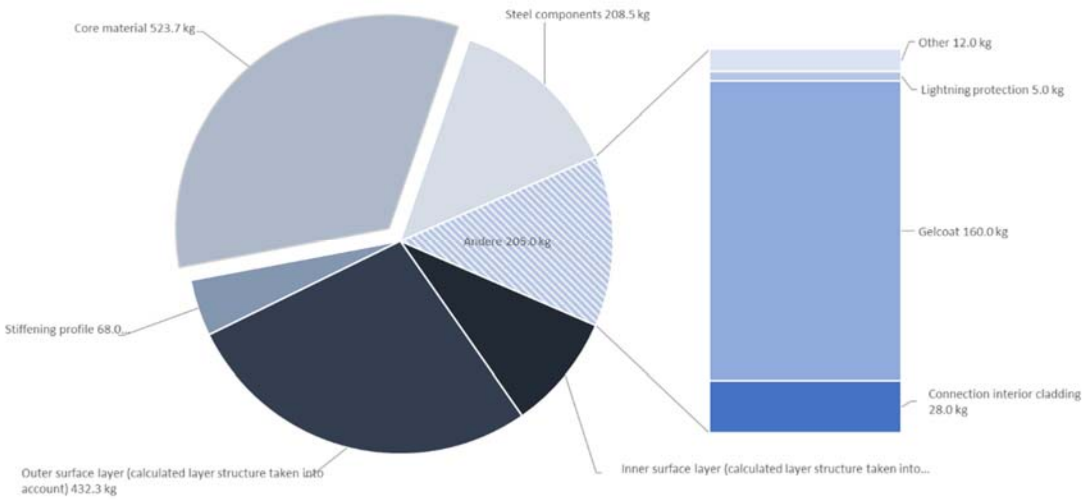

Figure 5: Masses of the roof assembly after adjustment of the core density

4 Conclusions and Contributions

In the faWaSiS project, the systematic approach made it possible to design and optimise a structurally relevant area of the car body, the roof structure, in FRP construction. As a result, 18 % of the mass of the roof structure could be saved compared to the reference steel-differential roof structure within the framework of a first prototypical demonstrator. With a change of the core material and further optimisation of the production, as well as with an additional optimisation step, e.g. optimisation of the individual layer sequence (shuffle optimisation) in the design, a mass reduction of more than 25 % can be achieved in the future.

Furthermore, it was possible to fulfil the required fire protection according to DIN 45545 Part 1 1998 [2] in this project by using the LEO® system from Saertex. The roof structure meets the requirements of HL3 R7 (exterior) and HL2 R1 (interior). With the help of the SHM system, it will be possible in the future to superimpose the highest load areas within the car body structure and thus lower the safety factors. This can lead to further mass savings [5].

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