



Eco-Design of Lightweight Structural Components for Electric Vehicles Made of Advanced Materials

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Abstract. The present paper showcases the results of the ALMA project, whose primary goal is to develop a novel electric vehicle structure for a passenger car, featuring reduced weight and environmental impact. Eco-design principles were incorporated from the early concept stages, integrating approaches like Design for Assembly and Disassembly (DFA/DFD), Design for Recycling (DFR), and functional integration of separate parts into a single structure. A FORD Mondeo with Internal Combustion Engine (ICE) was chosen as a design baseline. Subsequent redesign and material selection iterations led to the development of a novel multi-material Battery Electric Vehicle (BEV) concept, using Advanced High-strength steel (AHSS), low-density grade steel, laminate steel/plastic, and advanced Sheet Moulding Composite (SMC). Crash modeling was performed to virtually validate the design concepts against five different crash scenarios. Ultimately, the ALMA concept car's final design can now boast a mass reduction of 160.5 kg, translating to a 22% weight reduction compared to the baseline BEV.

Keywords: automotive industry · eco-design · electric vehicle · advanced materials · structural components · lightweight · composites · high strength steel · circular economy

1 Introduction

Increasing environmental awareness, as reflected in the recent European Green Deal [1], and concerns related to the growing material demand have motivated the automotive industry to explore new strategies for reducing the environmental impact of both their industrial activities and the entire life cycle of vehicles. In this context, the decisions made in the early stages of design play a crucial role in sustainability. These decisions encompass not only material and manufacturing selections but also extend their effects throughout the entire life cycle of the product, including end-of-life considerations [2].

ALMA is an EU project initiated in 2021 involving 9 partners from 4 different EU countries. The primary objective of ALMA is the development of a novel electric vehicle structure for a passenger car with reduced weight and environmental impact, achieved through the adoption of an integrated circular approach across the entire life cycle, supported by ecodesign principles, Life Cycle Assessment (LCA), and Life Cycle Costing (LCC) tools.

Advanced lightweight materials with structural performances, such as advanced high-strength steel (AHSS) grades, high-performance composites, and hybrid materials, were developed. Beyond lightweighting, other dimensions of the environmental footprint were considered, including efficiency in energy and material consumption, as well as end-of-life options (sorting, recycling, reusing, etc.).

This paper summarizes the eco-design approach followed during the project to select the “right material in the right place” to minimize the environmental footprint while maintaining cost-effectiveness and manufacturability.

2 Methodology

The project commenced with a detailed assessment of the environmental aspects affecting the product from a circular perspective, incorporating cost considerations as a core action to guide subsequent tasks. A Ford Mondeo with Internal Combustion Engine (ICE) was chosen as the starting point. The initial step involved transforming it into a full Battery Electric Vehicle (BEV) version, serving as the baseline for evaluating the achievement of the goal—specifically, a 20% reduction in weight. The project scope encompassed the body-in-white (BIW), chassis, and closures.

The newly transformed BEV baseline design underwent validation through Crash CAE under 5 critical load cases, ultimately reaching a final weight of 727.47 kg. Therefore, to achieve the 20% weight reduction, the weight target for the ALMA ecodesigned structure was set at 581.92 kg or lower.

The baseline was analyzed to identify parts and subsystems subject to modifications, utilizing the innovative materials proposed in ALMA: advanced High-Strength Steel (HSS), low-density grade steel, laminate steel/plastic, and advanced Sheet Moulding Composites (SMCs).

The first criterion was meeting technical requirements in terms of crash behavior. An initial assessment was conducted to identify parts that should remain unmodified, those that could benefit from advanced steels, and those that could potentially be produced using either SMC or other steel grades.

In cases where different materials were eligible, the decision to use the “right material in the right place” was made considering the following metrics:

- Weight saving, expressed as kg saved compared to the baseline part
- Circularity, where a score was assigned based on recyclability potential, ranging from 1 (“currently not recyclable”) to 3 (“easily recyclable”)
- Number of references saved
- Assembly line compatibility, assigning a score from 1 (“significant changes are required”) to 3 (“no changes required”)

BEVSIM allows users to measure and compare impacts resulting from design alternatives, lightweight designs, materials, or subsystem choices, recycling technologies, end-of-life scenarios, and future scenarios resulting from changes in electricity grid mixes. This enables easy comparison of complex trade-offs between materials that may be lighter and more sustainable during use but environmentally more costly during production and end-of-life. BEVSIM can also perform various types of impact assessments, including life cycle hotspot analysis, impact assessment, circularity assessment, and economic impacts analysis.

3 Results

In several systems, particularly in those with high mechanical requirements, steel was the only viable solution in terms of crash behaviour. For such parts, different cases were identified:

- Unchanged steel parts: Some of the parts were not modified when there was no alternative material to propose that could fulfil the technical requirements or the lightweighting potential did not justify the change.
- Steel parts with the same geometry as the baseline but lower thickness: The use of more performant steel grades resulted in a reduction of thickness and associated weight saving. There was no need to change the shape, and no possibility to integrate other functions.
- Steel parts with integration of functions: In this case, the use of a more performant steel grade opened new integration possibilities. Systems composed of several parts in the baseline design could be integrated to reduce the references significantly. The systems chosen for integrated redesign were the door panels and the H-Frame structure.

However, some systems could potentially be produced either with SMC or steel, and the choice required a more detailed analysis. Those systems were the dash panel, the rear floor panel, the rear tray, and the battery lid (Fig. 1).

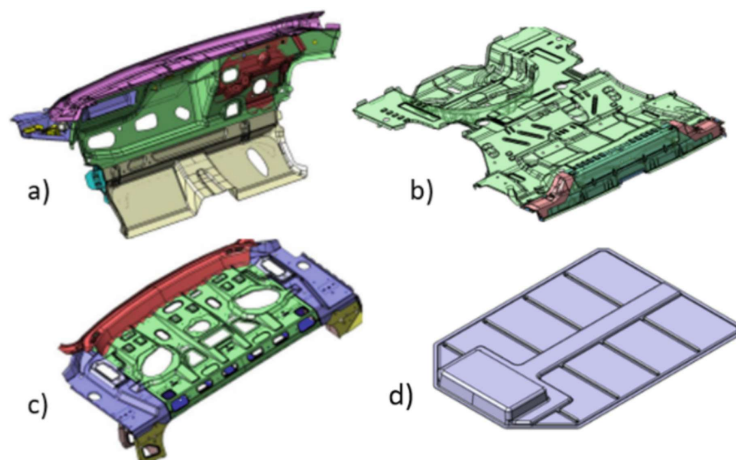


Fig. 1. Images of the considered systems to select SMC vs Steel. a) dash panel b) rear floor panel c) rear tray d) battery lid.. Image produced by the authors using CATIA v4 CAD software.

For these systems, a detailed analysis was made considering the metrics described in Sect. 3. The results are shown in Table 1.

This assessment was complemented by a sustainability analysis using BEVSIM (Fig. 2).

Table 1. Assessment of potential materials for different sub-systems

	Weight saving		Circularity		n° References saved		Assembly line compatibility	
	Kg-saved compared to the baseline		1 “currently not recyclable” 2 “difficult to recycle/disassemble” 3 “easily recyclable”		n° of references saved		1. “Significant changes are required” 2. “Minor changes are required” 3. “No changes required”	
	Steel	SMC	Steel	SMC	Steel	SMC	Steel	SMC
Dash panel	3,01	5,93	3	1	0	11	3	2
Rear floor panel	17,04	14,09	3	1	0	2	3	2
Rear tray	1,60	3,35	3	1	0	6	3	2
Battery lid	19,84	24,50	3	2	0	0	3	2

The selection of materials for each system was done accordingly:

- The dash panel benefits most from the use of SMC. A drastic reduction in references is possible, with a significant lightweighting potential. The steel option not only maintains the number of references but also has a higher CO₂ eq. Intensity, according to BEVSIM analysis. Therefore, this component was selected to be redesigned using SMC materials.
- The rear floor panel in SMC has a lower lightweighting potential than the steel option, which uses a steel laminate. SMC is also more damaging to the environment, according to BEVSIM. It was agreed to select the steel option for this component.
- The rear tray has a lower lightweighting potential for both options. In terms of sustainability, the steel option is less damaging, as shown by the BEVSIM tool. Additionally, no significant changes in the assembly line are needed, while the SMC option would require specific adhesives to withstand an E-coat bath. It was decided to design the component using advanced steel.
- The battery lid has a higher lightweighting potential for both options, and their environmental impact is similar. Since it is assembled after the E-coat process, the SMC allows for the use of debondable adhesives. Therefore, it was agreed to design it using a flame-retardant SMC.

The bill of materials was then completed, and the new total weight of the ALMA structure was reduced to 567 kg. Finally, the new design was validated using CAE

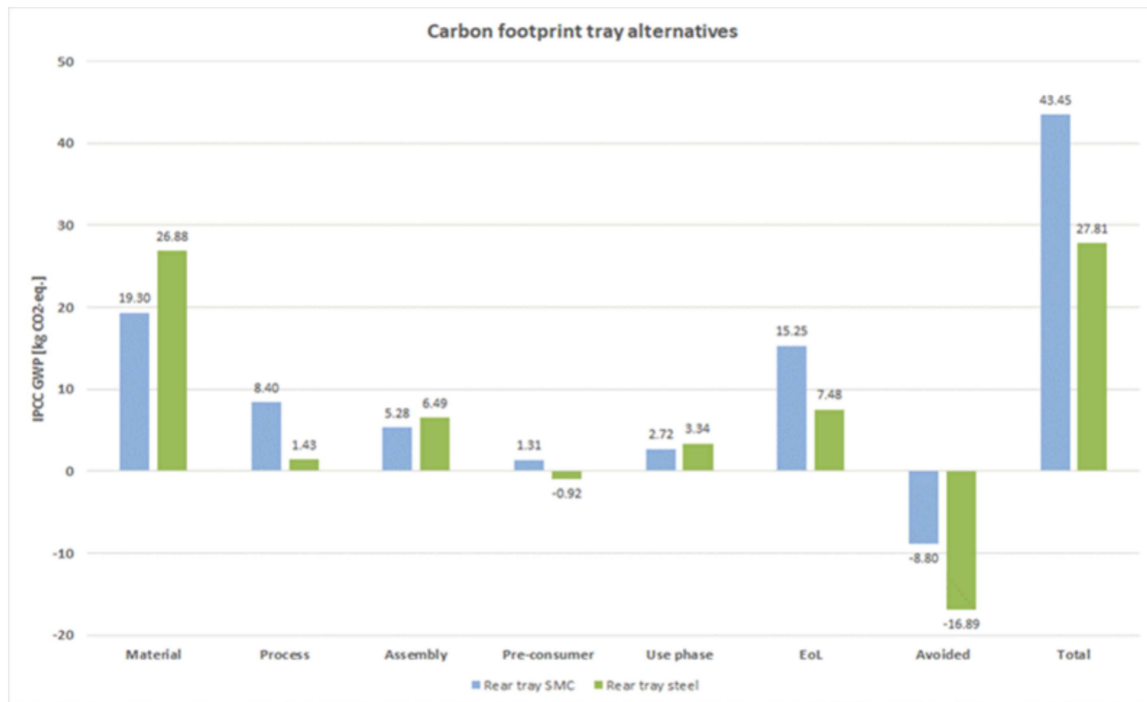


Fig. 2. Example of sustainability analysis comparing SMC vs steel for the rear tray per life cycle stage. “Pre-consumer” considers recycling of pre-consumer production waste.

analysis for 5 crash scenarios and iteratively modified until reaching a validated structure with a 22% reduction in weight (160.5 kg less than the baseline), contributing to a total reduction of 1850 kg CO₂-eq.

4 Conclusions and Future Work

The ALMA project adopted an integrated circular approach across the entire life cycle to design a multimaterial BEV structure, optimizing the selection of materials and production processes to achieve a more efficient and environmentally sustainable vehicle structure. This approach produced a new design that resulted in a 22% weight reduction from the baseline while still being able to fulfil the crash requirements, as demonstrated by CAE analysis. The carbon footprint was reduced by 24%, thus fully validating the usefulness of the approach for producing more sustainable vehicle designs.

In the last months of the project, several demonstrators will be prototyped to show the feasibility of such results.

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More information about the project: <https://almaproject.eu/>

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