

Mass Reduction Potential of Steel and Aluminum in Automotive Applications

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ABSTRACT

In this paper the mass reduction potentials of steel and aluminum in automotive applications are compared. In order to determine the mass reduction potential of each material, several applications and concepts are analyzed. This is done by evaluation of the mass and the performance of these components. The results are computed based on theoretical mechanical fundamentals and vehicle requirements.

The analysis of a series of body structures indicates that aluminum may achieve 11 % to 34 % mass reduction depending on whether it is compared to recent optimized steel designs or to former (non-optimized) steel designs.

A hood benchmarking [3] study pointed out, that the substitution of steel by aluminum allows a mass reduction of approximately 36 %. This mass reduction goes along with a material cost increase. Aluminum is primarily used to decrease the mass. But, on the other hand, it is also possible to design steel bumpers that are up to 8 % lighter than a corresponding aluminum bumper.

The experimental analysis of front structures shows that a lower mass for this area of approximately 18 % is possible with aluminum. This finding is also associated with a higher number of parts (+18 %) and higher costs for material, forming and assembly (+59 %). It is also possible to decrease mass even more by using an optimized steel design. A mass reduction of about 22 % for a bumper rail system compared with a steel reference system is possible. With the steel solution, the number of parts is also decreased. [9]

INTRODUCTION

In recent years materials selection in passenger vehicles has become more and more important. Vehicles have historically been predominately made of conventional steel. The competition between OEMs and governmental demands for safer, lighter and more fuel

efficient cars has led to the market entry of new materials such as new high-strength steels or aluminum.

In this paper the potential mass reduction impact of aluminum and new steels in comparison to conventional steels is examined. Two common industry statements prompted this analysis.

1) Mass can be reduced by 25 % through the application of modern high-strength and advanced high-strength steels. [1]

2) Mass can be reduced by up to 50 % by the application of aluminum. [2]

The baseline against which these mass savings are claimed is usually a former steel vehicle design from the 1990's era. What is often overlooked is that today's vehicles can contain up to 90 % high-strength (HSS) or ultra high-strength steels (UHSS) and the structure can be optimized to take advantage of the high strength properties. Both high-strength steel and aluminum are growing in use in vehicles today. The way of thinking seemed to be established that aluminum is the lighter solution in any application, when not considering the costs. Therefore the question, if this is true, is analyzed in this study as well.

In order to establish fundamental reference points, a detailed description of material characteristics and basic structural behavior for different materials is studied in this paper. Several vehicle body structures and components made of steel and aluminum are analyzed and compared concerning their mass reduction potential. To compare the mass in a neutral way, the performance of the body structures and components are also evaluated.

Concept cars like the UltraLight Steel Auto Body (ULSAB), the Arcelor Body Concept (ABC) and the ThyssenKrupp NewSteelBody (NSB) are summarized, showing mass reduction potential, performance and costs of optimized steel. No aluminum concept cars with

sufficient data are available. Furthermore, the vehicle mass development in the time period between 1990 and 2005 is shown. The mass of steel and aluminum components such as hoods, bumpers and front structures are compared based on similar performance. More than former analysis likely do, this study is based on a fundamental, widely spread and scientific structured data basis.

FUNDAMENTALS

Typical load cases have been considered to represent the mechanical requirements of body structures. These include torsion stiffness, bending stiffness, 3-point-bending strength and tensile strength. Considering these load cases a broad bandwidth of steel and aluminum material grades were analyzed for mass and package space. The examined materials are listed in Table 1.

Material	Steel				Aluminium		
	Mild 140/270	HSLA 350/450	DP 500/800	MS 1250/1520	5457 O	6060 T6	7021 T6
Modulus of elasticity [N/mm²]	210000	210000	210000	210000	72200	72200	72200
Tensile strength [N/mm²]	270	450	800	1520	130	245	430
Density [g/cm³]	7.85	7.85	7.85	7.85	2.7	2.7	2.7
Poisson number [1]	0.3	0.3	0.3	0.3	0.34	0.34	0.34
Modulus of shearing [N/mm²]	81000	81000	81000	81000	26900	26900	26900

Table 1: Material data

The mechanical properties derived from each load case are shown in Figure 1. With these parameters the ratios of required package space and mass are determined for the different material grades.

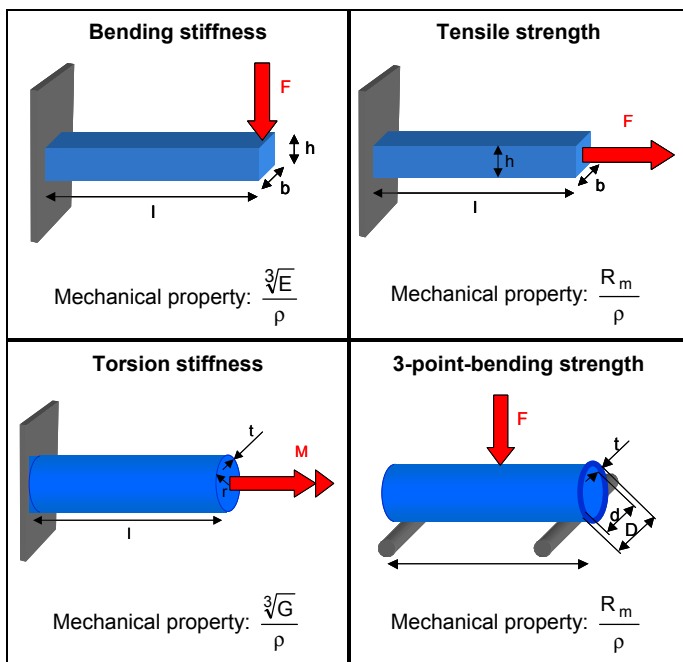


Figure 1: Mechanical properties of load cases

All fundamental analysis results are summarized in Table 2. The table shows that bending and torsion stiffness of an open profile aluminum section requires about 1.4 times more space at the same performance. At the same time aluminum reduces mass by 50 % in reference to a steel profile with equal performance. For torsion stiffness of a closed profile, three times the package space is required for aluminum than for a steel tube of the same performance. In this load case the closed steel tube has the same mass as the aluminum tube.

	Package (h/h _{ref} resp. t/t _{ref})							Mass (m/m _{ref})						
Material	Steel				Aluminium			Steel				Aluminium		
Material grade	Mild 140/270 (reference)	HSLA 350/450	DP 500/800	MS 1250/1520	5457 O	6060 T6	7021 T6	Mild 140/270 (reference)	HSLA 350/450	DP 500/800	MS 1250/1520	5457 O	6060 T6	7021 T6
Bending stiffness	1.0	1.0	1.0	1.0	1.4	1.4	1.4	1.0	1.0	1.0	1.0	0.5	0.5	0.5
Tensile strength	1.0	0.6	0.3	0.2	2.1	1.1	0.6	1.0	0.6	0.3	0.2	0.7	0.4	0.2
Torsion stiffness (open tube)	1.0	1.0	1.0	1.0	1.4	1.4	1.4	1.0	1.0	1.0	1.0	0.5	0.5	0.5
Torsion stiffness (closed tube)	1.0	1.0	1.0	1.0	3.0	3.0	3.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
3-point bending strength	1.0	0.6	0.3	0.2	2.1	1.1	0.6	1.0	0.6	0.3	0.2	0.7	0.4	0.2

Table 2: Package and mass ratio based on reference

Concerning tensile strength and 3-point bending strength, martensitic steel (e.g. MS 1250/1520) weighs as much as aluminum 7021 T6. Both materials are at equal performance, 80 % lighter than mild steel. A difference between martensitic steel and aluminum 7021 T6 can be found regarding the package. Martensitic steel requires 80 % less package space and aluminum 40 % less package space than mild steel.

The results show that, in general, aluminum has a higher package space demand than steel at equal performance. For the mass ratio the result depends on the specific load case. Concerning bending and torsion stiffness, an open aluminum profile can have half of the mass of a steel profile. Regarding the other load cases, steel and aluminum have similar mass reduction potential.

BODY STRUCTURE ANALYSIS

In actual vehicle body structures, where load cases are much more complex than the simple cases shown above, so the comparisons between materials are more difficult. There are no available direct comparisons of vehicle structures in the literature. However, this paper evaluates current production and concept vehicles in both steel and aluminum design and makes mass