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Body Design in Electric Microcars: A Review

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Abstract **–** As the world is running out of fossil fuels and the environment is being seriously damaged by the combustion residuals of the internal combustion engines, the world countries have begun to search alternative ways for mobility. Lightweight electric vehicles with low energy consumption values are seen as one of the strongest candidates of future mobility. As the smallest versions of road vehicles, microcars are totally suitable for electric vehicle technology, with minimum energy consumption values due to their minimalistic designs. They reduce the energy consumption values when they also save the redundant sizes of conventional personal vehicles. Thus, they are also considered as an alternative solution to the expanding traffic jams in major cities. Body design for an electric vehicle also has a great importance since its weight reduction directly affects the vehicle driving range. Vehicle body is a larger design domain for the mass optimization, rather than the other parts. In this study, methods for design and optimization of a microcar body are introduced, which apply to weight reduction by removing materials from unloaded or relatively less loaded regions and makes an optimization between the mass and stiffness. Comparisons are also made between the materials which could be used and currently being used in microcar bodies in terms of strength, weight, and price.

Keywords **–** *Microcars, lightweight design, vehicle body design, future mobility, clean energy, optimization*

I. Introduction

With the growth in the population, the current transportation vehicles, which mainly consist of personal vehicles have started to cause expanding traffic jams, especially in major cities. Despite their role in the improvement of life comfort and quality, the problems of conventional vehicles with internal combustion (IC) engines are not only limited with their contribution to air pollution. Conventional personal vehicles contribute also to road and street congestion, as well as the increase in noise in urban complexes. It is expected that the solution of these problems may be achieved by wider use of public transportation. However, due to some limitations of public transportation, such as limited network and passenger capacity, fixed departure times and etc., public transportation may not be sufficient for everybody. Instead, small electric city cars could be an alternative to public transportation. These small electric vehicles, termed as microcars, are noiseless and less harmful to the environment while causing smaller congestion and offering more flexible conditions rather than public transportation due to their minimalistic designs [1].

Microcars are the smallest versions in the automobile classification and could be built using the electric vehicle technology, without the problems that usually occur while converting conventional vehicles into electric, thanks to their lower power and energy consumption requirements [2].

The microcars are nearly as old as conventional vehicles. Their first applications in history are the cyclecars, which were more affordable versions of conventional 4-wheel vehicles at that date, which are not that accessible due to their high costs. Cyclecars were usually constructed from readymade motorcycle parts, which were directly mounted to a lightweight chassis. Their popularity was at the top in period 1910-1914 [3].

The chassis of these cyclecars must have been lightweight, because of the low power and torque values of motorcycle engines. And this reduced design requirement in cyclecars allowed alternative chassis configurations. Thus, while body-on-frame designs were the preferred choice in cars, monocoque wooden frames were common in cyclecar design. Figure 1.1 shows the lightweight body of a cyclecar [4].

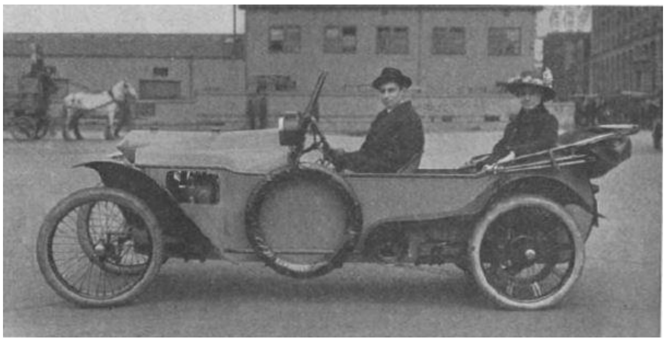
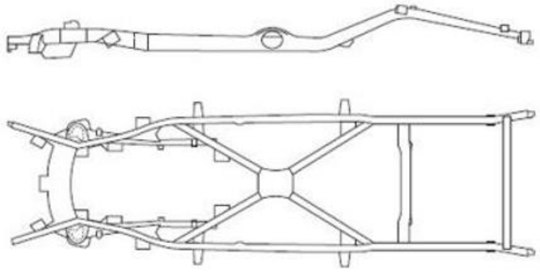


Fig. 1.1 Lightweight cyclecar chassis used with two-cylinder air cooled engine [5].

II. Chassis of a Microcar

In the early cars, chassis and bodies were separate items. The task of the chassis was to provide the basic strength and rigidity to the vehicle, while the body was responsible for the safety of the passengers and the luggage by providing a shelter against the outside effects [6]. The advantage of this type of chassis is the simplicity of the design, being easy to manufacture and hence the affordable costs. Because of these reasons, early microcars were economically accessible, and the majority of people could afford the prices of these cars. Designing of monocoque vehicle bodies is more complex than the separate chassis, and back at these dates body designs and vehicle technology were not so high enough to design these cars as cheaply as separate chassis and body. Despite their complexities, monocoque space frame vehicle body designs have some advantages, which are the reason for preference of such designs. These advantages could be list as the rigidity of the construction and the reduced mass since loads of the chassis are uniformly distributed to the whole body. In Figure 2.1 ladder frame of the separate chassis and the space frame structures are shown.



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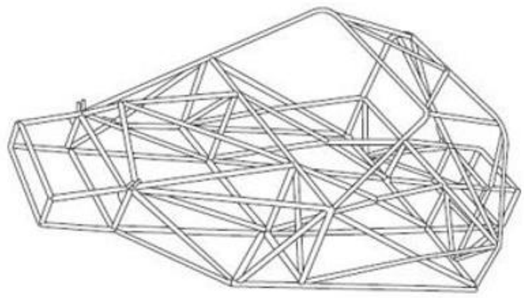

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Fig. 2.1 Ladder frame structure (a) and the space frame structure (b) [7].

Unlike conventional vehicles with IC engines, electric vehicles require a much lighter body design to ensure a high range like conventional vehicles. Besides that, they must be rigid and resistant against impacts. In order to satisfy rigidity and resistance requirements while keeping the weight low, optimization methods are applied on the small electric vehicle bodies. These methods increase rigidity while reducing volume from slightly loaded spots. In Figure 2.2a and 2.2b, body in white (BiW) designs of microcars is shown. Figure 2.2c illustrates the passenger volume requirement in a small electric vehicle.

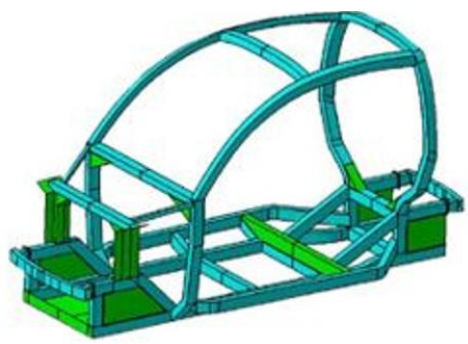
Requirements of a small electric vehicle body could be listed as [6]:

- Lightweight
- Minimum amount of parts
- Enough volume left for passenger and luggage cabin
- Isolated from vibration
- Rigidity

III. Analysis and Design of the Chassis

A. Load Cases

The loads acting on the chassis or body structure divide into 4. These loads are bending loads, torsional loads, lateral loads and longitudinal loads that occur during acceleration and braking. For the intention of simplicity, these cases are usually taken into account separately and then superposed. In this study, in order to simplify the model, the superposition of only bending and torsional loadings are considered [7].



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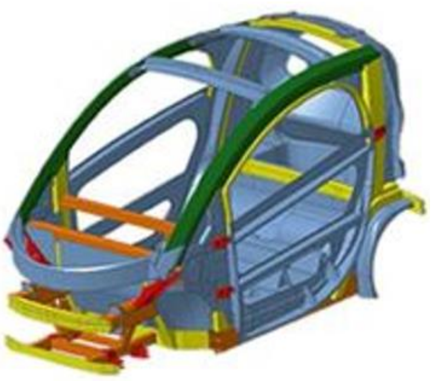

b

c

Fig. 2.2 Rigid microcar BiW CAD models (a [8] and b [9]), and the required passenger volume inside the body (c [10]).

The bending scenario depends on the weights of the major components of the vehicle. These weights could be treated as distributed loads and mainly consist of bumpers, electronic components (such as motor controller, batteries, passengers) and etc. in a microcar body. The vehicle chassis could be treated as a two-dimensional beam like structure if the vehicle is approximately symmetric about the longitudinal x-axis. Torsion scenario mainly occurs, when the vehicle is moving along on an uneven road surface, and there is an altitude difference between the wheels of an axle. However, this is an extreme scenario, and especially in urban complexes, where vehicles moving in on-road conditions, it is not common. Instead, torsion load occurs more often, when the vehicle turns into a radius, and the wheels experience a load transfer from the inner wheels to the outer wheels. It must be emphasized that, torsion load never exist on its own, since the vehicle is always subjected to bending loads, due to its own weight, as long as it is under the influence of earth's gravity. However, to ease calculation, the torsion and bending scenarios are superposed as mentioned before. Figure 3.1 illustrates these load cases.

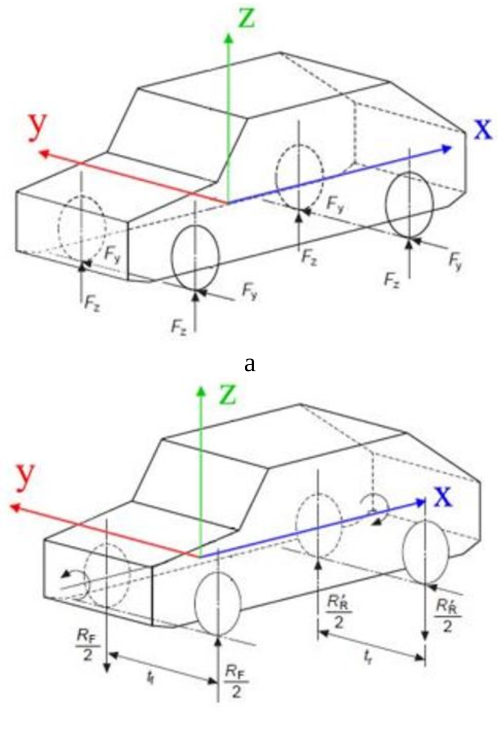

Fig. 3.1 Bending (a) and torsion (b) loads acting on the vehicle [7].

B. Analysis and Optimization Process

Applying bending loads and torsional loads to the chassis and the body geometries with the analytical method is not straightforward. Especially when the design considerations such as mass and volume discretization as well as leaving passenger cabin enough volume need to be taken into consideration. The analytical method could be very troublesome to apply and would be inadequate when optimization is required. In order to acquire design goals by applying design conditions, use of numerical approaches comes handy.

Figure 3.2a shows a finite element (FE) model of a vehicle body. On this model, relative less loaded regions are removed from the model by using topology optimization method. This optimization results with a volumetrically reduced and stiffer geometry. In order to increase the stiffness, a tube section is chosen as an initial design. The results of the optimized body after topology optimization are shown in Figure 3.2b, 3.2c and 3.2d.

IV. Materials

Materials used in a vehicle body have a major impact on vehicle weight, as well as the body strength and rigidity. In electric vehicles, weight is an important parameter, which affects the range and the performance of the vehicle. Generally speaking, every one-kilogram weight loss brings approximately 3 km extra range along. In order to raise the range of a vehicle, besides the material distribution and weight reduction optimizations, altering the material type to a lighter material could also be a solution, as long as these materials also satisfy the previously introduced tasks, which the body part must ensure. Hence, the range could be improved without increasing the battery capacity. Availability and cost are also important parameters while choosing the applied material to the body [12].

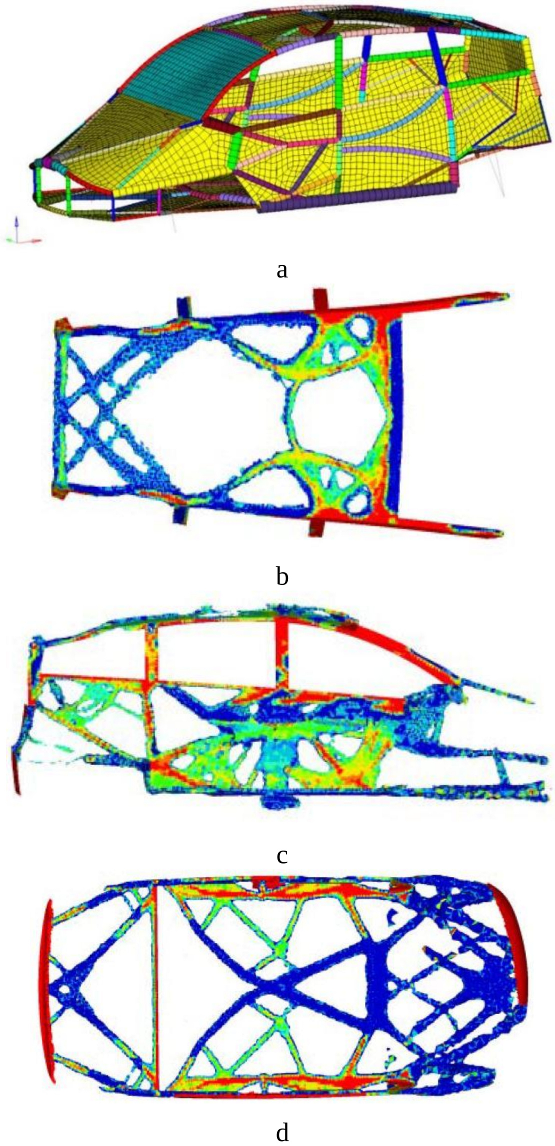

Fig. 3.2 FE model of the BiW of an electric vehicle (a) and the topology optimization results from roof (b), side (c) and bottom (d) views [11].

Essentially, applying the proper material to the vehicle body has 4 main steps: specification, analysing, sorting and research. During the specification, the requirements and expectations that a material must satisfy are stated. The inadequate candidates are eliminated in the analysing step. The remaining materials are sorted and evaluated in analysing step. And finally, in the research step, detailed properties of materials are analysed. Then the vehicle body material is then applied [13].

Recently the main material types used in vehicle bodies are steel, aluminium, composites, and magnesium [14]. An average passenger car contains approximately 75% metals, which consist of mainly low carbon steel [14]. It is predicted that the material distribution of vehicles will be made of 55% metals, 18% plastics, 7% rubber, and remaining parts of a variety of other materials by 2020.

More efficient use of steels has a part on weight reduction since steels and die-cast steels cover the 3/4 part of an average vehicle. One reason why steels are so common in the automotive industry is the impact damping properties of the steels [16]. Besides that, high forming and bonding capabilities have become the main reasons for wide steel use in the automotive industry. Nonetheless, designers try to reduce the use of steel and replace them with lighter materials due to the high densities of steel materials [17].

The recent researches focus on the use of aluminium in the automotive industry. Aluminium provides a lighter construction, thus it is expected that increased aluminium use in car bodies will reduce the weight seriously. A saving of 20% to 30% in total car weight could be made by changing the steel use into aluminium use [18]. Aluminium could be applied to the additional chassis systems, such as drivetrain and suspension system elements, as well as the body. In the body, aluminium is manufactured likely to the steel applications, and with the recent developments in welding technology, other aluminium parts can be manufactured with extrusion and welding [19]. Aluminium car bodies are shown in Figure 4.1.

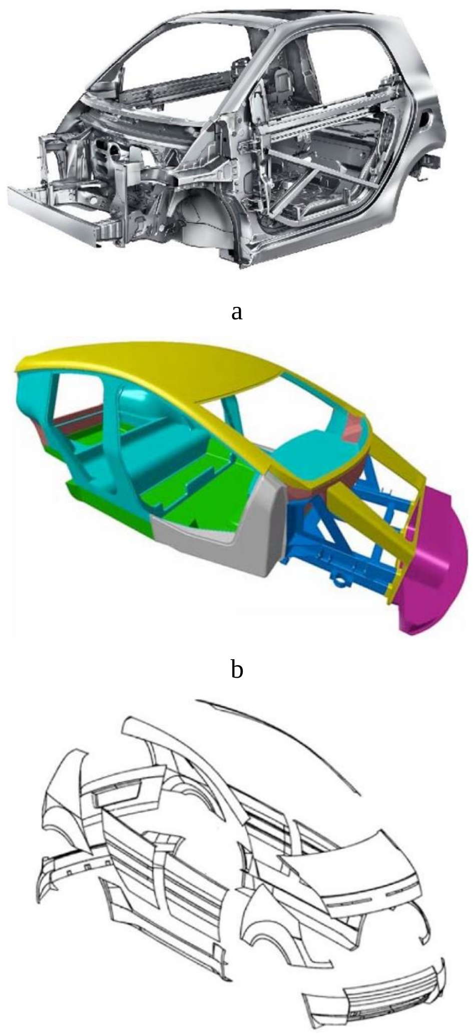

Fig. 4.1 A lightweight microcar body made of aluminum (a [20]), aluminum/composite front sub frame (b [21]), and exterior panels (c [21]).

Magnesium is applied to the automotive bodies as an alternative to steel, cast steel, and aluminium, because of the strength properties although its low density. Taking into account its density value of 1,8 (gr/cm3), while this value is approximately 7,2 in steel and 2,7 in aluminium [22]. Note that, owing to its one quarter density value compared to the steel, magnesium lowers the weight of the car by 75%. In slender sections, magnesium highly resists to the bending, ensures rigidity and energy absorbing features while reducing the weight [23].

Composites, namely fibre-reinforced plastics, bring along the features such as the strength, corrosion resistance, and impact damping, with fewer density values. The disadvantages of composites can be listed as the high prices, low production rates, and the difficulties with recycling [24]. These facts show that proper material use and distribution could save a serious amount of mass on the vehicle body. Figure 4.2 illustrates the reduced weight of a vehicle, and the change of vehicle parts percentages.

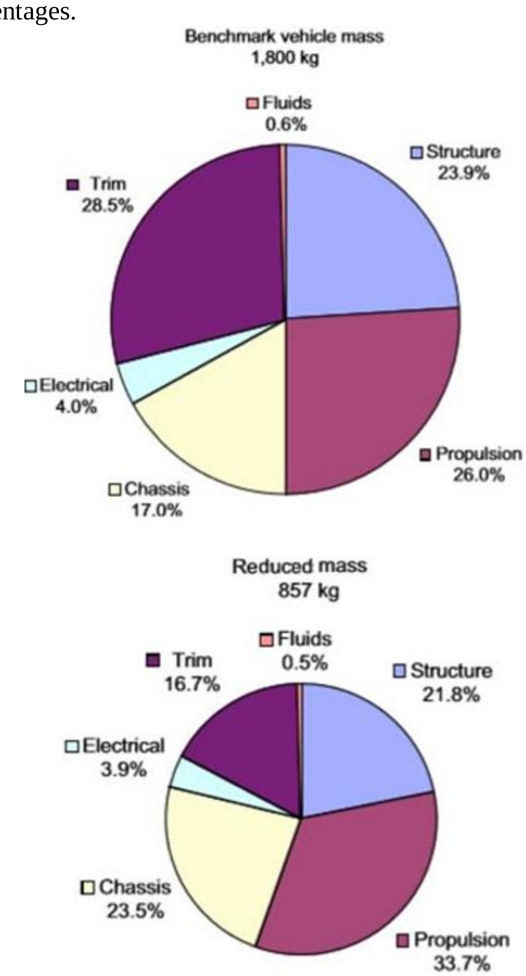

Fig. 4.2 A weight reduction applied to a vehicle by changing the distribution of material use in percentages [21].

V. Production Costs

According to Advanced Volume Automotive Composite Solution (AVACS) data, the cost of production of a vehicle body is approximately 4087 $, when a production volume of 50.000 vehicles. And it is expected that, with the increasing production volume, the cost per volume will decrease continuously. Figure 5.1 shows the costs in production line of a car body [21].

A lightened car body results in lower production and running costs, as well as an increased driving range. In Figure 5.2, different hybrid and fuel cell vehicles are compared in terms of mass, fuel type, cost and driving range.

Since cost is an essential issue of automotive design and production, material usage depends on it, despite the importance of material properties. And this is one of the biggest obstacles to use of advanced composites. These composites, such as carbon-reinforced polymers seem to be one of the best alternatives of steels in vehicle structures.

Approximately 60% of weight could be saved if all steel structures replaced with composite materials. However, the cost of these materials is about 11-22 $/kg, where the same value is about 1-1.3 ($/kg) for the steel [21].

Apart from its cost, the main design criteria of a material to be used in a car body are its stiffness and mass. Thus aluminium and carbon-fibre composites with their stiffness/mass properties seem to be the best alternatives to the steel. Cost per stiffness values of carbon-fibre composites are higher than aluminium, nevertheless, considering the other factors such as weight saving potential, cost savings, and lower tooling costs make carbon-fibre composites more feasible than aluminium use applications. A detailed comparison in terms of stiffness, density and cost is made in Figure 5.3 [21].

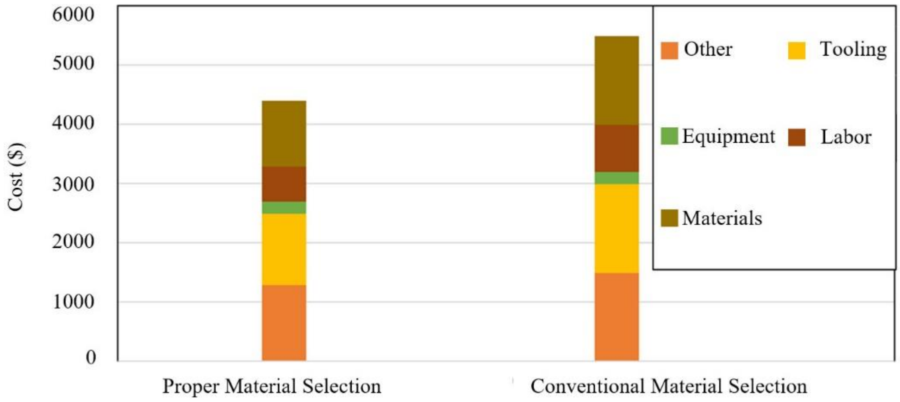

Fig. 5.1 Effect of proper material selection to the cost of each parameter (according to [21]).

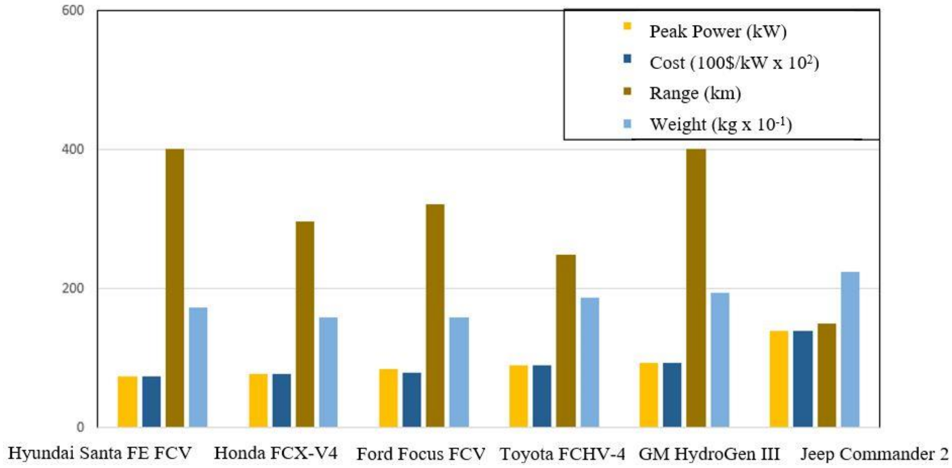

Fig. 5.2 Comparison of different hybrid and fuel cell vehicle costs in connection with power, range and weight (according to [21]).

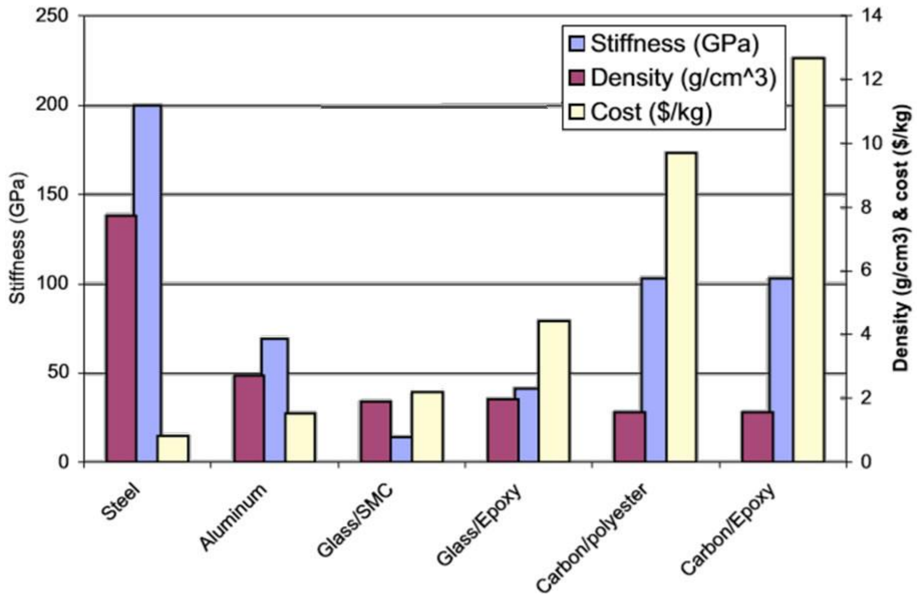

Fig. 5.3 A weight reduction applied to a vehicle by changing the distribution of material use in percentages [21].

VI. CONCLUSION

Although the effects of the mass on the performance and energy consumption are common design problems of electric and IC engine vehicles, those effects on the driving range are much greater problems in the design of electric vehicles, compared to the IC engine vehicles. Especially in electric microcars, in which it is aimed to consume energy as efficiently as possible, a lightweight design is essential. Thus, the automotive manufacturers focus to reduce the mass of the vehicle in every possible way. Optimization of structural parts based on the stress concentration has an important role in weight reduction. Furthermore among all the structural parts, the chassis and body part is not only a wide design area, where a large amount of mass reduction takes part, but also reasonably suitable for the optimization. Since the body part must ensure rigidity and be also lightweight, an optimization based on stress distribution can be used to minimize the mass, and maximize the stiffness. In this study, the basic tasks which must be ensured by the body of a microcar are introduced, analysis and optimization methods for a vehicle body are essentially given. The effects of material selection on material strength, mass, and production costs for different material types used in vehicle body are also analysed.

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