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Analysis of Energy Saving and Emission Reduction of Vehicles Using Light Weight Materials

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Abstract

As the result of energy saving and emission reduction, there is a way to reduce weigh of vehicle in order to reduce the consumption of gasoline. This paper is mainly devoted to several lightweight materials and technical methods in automobile applications, and introduces a new approach to lightweight materials instead of mild steel. It is concluded that lightweight materials will be widely used in the automobile industry if the costs of lightweight materials are as much as traditional materials.

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Keywords:lightweight materials; energy saving; emission reduction; electric vehicles

1. Introduction

In recent years, the energy conservation and environmental pollution become a serious concern around the world now. Europe and many countries have made new laws or regulations on automobile development and sales, aiming to reduce the CO_2 emission. They are researching and developing the use of electric vehicles to reduce fuel consumption and exhaust emissions. Many engineers study how to increase the battery capacity to increase vehicle mileage. However, electric vehicle has an outstanding problem in use that the car is very heavy because of the battery weight and body structure, so that electric vehicle mileage decreases. Unfortunately, how to reduce weight has been neglected for a long time in previous works.

This paper focuses on the method to reduce the weight of vehicles, introduces a method to reduce the weight of vehicles using lightweight materials and analysis the advantage of application of lightweight materials. As the result, the lightweight materials will have a great potential to replace traditional materials.

2. Lightweight design methods

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Road traffic generally moves at permanently changing speeds. The influence of mass acceleration can be clearly seen from the example of the fuel consumption figures calculated according to the ELA (European Legislative Average) (Figure. 1). The influence of vehicle mass on fuel consumption depends more on the kind of the engine than on the category of the car.

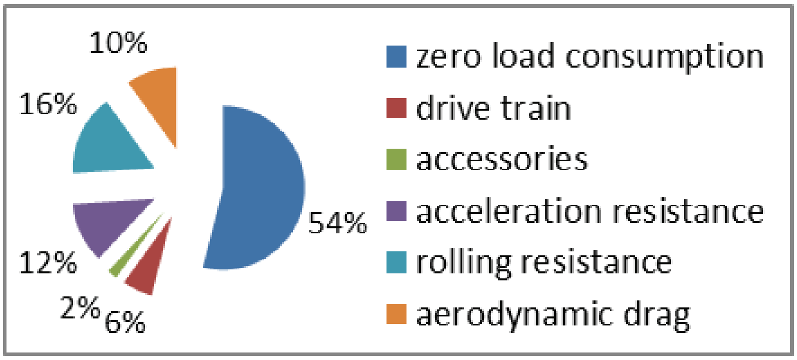

Fig. 1. Impact of vehicle weight on NEDC（New European Driving Cycle）

To escape from this vicious circle car manufacturers are forced to take action in the form of lightweight concepts. Car bodies contribute 25% to the total weight of a car and offer an appropriate way of breaking this circle[1]. Light metals are seen as a promising opportunity to decrease the body in weight decisively.

Aluminum has some properties that make it interesting for bodies in automobile applications. The strength of aluminum sheet panels and extruded sections is approximately same as that of steel body panels. That means to achieve a certain permanent distortion or a break of the panel, the same force must be applied in processing cycle. In addition, the density of aluminum is 1/3 the density of steel. However, the rigidity of aluminum is lower than that of steel. The effect is that aluminum has a higher elastic distortion when exposed to the same force as steel.

Magnesium is 33% even lighter than aluminum and 75% lighter than steel or cast-iron components. The corrosion resistance of high-purity magnesium alloys is better than that of conventional aluminum die cast alloys. Magnesium alloys have distinct advantages over aluminum and ferrous materials by virtue of better manufacturability. Solidification is faster due to lower latent heat so that approximately 25-50% more castings can be produced per unit time compared to aluminum[2].

Steel, as the traditional automotive materials, has proved its value. More and more new high strength steels are used for high strength stress parts now. High strength steel sheet can be used in auto body to improve components impact energy absorption capacity and resistance to plastic deformation[3]. Comparing with aluminum, magnesium, and composite materials, high strength steel has better economy in that its raw material and fabrication cost are cheaper.

This paper focuses on the application of aluminum alloy in the automobile, and calculates the energy saving by using mathematical models.

3. Analysis and results

Aluminum parts may be highly complicated in their design due to the high number of design solutions like the previously mentioned extrusions and castings available in nearly any shape. One casting can replace a complex part consisting of several steel panels. Consequently a reduction of parts up to 50% is feasible[4]. Practical experiences with measurements, clearances and behavior of aluminum in car body applications are fairly rare so far and hence almost no reference values are available.

Crash tests are more and more important since occupant safety is a feature that is receiving considerable public attention. Tubular aluminum sections crumple in the ideal way when subjected to impacts. They develop a crumple pattern that can absorb more energy than equivalent steel elements. Consequently, with half the weight of steel an aluminum structural member provides the same safety[5]. Another advantage the aluminum body implies is that a lower mass of a moving vehicle develops less kinetic energy and therefore protects other road users in case of a crash.

The environmental aspect of different materials can be assessed by a comparison of the energy household of an aluminum-made and steel-made car during production and over their whole lives. Only having regard to all processes that cause energy consumption during production and operating life, can an accurate result be given of the eco-friendliness of a car. It includes material cycles and the amounts of energy needed to produce and maintain a vehicle during operating life time, including fuel.

Undoubtedly aluminum is more expensive to manufacture than steel. The costs of a sophisticated aluminum car body like that of the Audi A8 are many times larger than of a traditional steel body.

A further comparison can be made in terms of carbon dioxide emissions. If primary aluminum is used it takes 90000 km until the lighter aluminum auto has compensated the higher CO_2 emission during production. However, when the proportion of recycled increasing, secondary aluminum exceeds 75% the CO_2 emission household is positive for aluminum.

3.1. Calculation of fuel consumption and emissions

The structure size optimization is one of the earliest and most mature applications in automobile lightweight technology. It generally takes the size of the auto parts, such as the wall thickness of the stamping parts, the size of the beam section, the size of the lightening hole, and other parameters as the design variables, In order to meet the different conditions of stiffness, strength, vibration, energy absorption, and etc as the constraint conditions. The optimization model is built with the minimum structure quality as the objective function, and its mathematical expression is:

$$\begin{cases} \min \quad m(x) \\ \text{s.t.} \quad u_k \le [u] \\ \sigma_{max}(x) \le [\sigma] \\ f_n(x) \ge [f] \\ E(x) \ge [E] \\ \text{d.v.} \quad x_L \le x \le x_u \end{cases} \tag{1}$$

Where, m is mass of car; u_k is displacement of node k; σ_{max} is maximum stress; fn is frequency of n; E is energy absorbed by structure in collision; x is size variable vector; the numerical value within the brackets is the scope of the constraint function.

Previous studies have shown that 1kg aluminum of application in automobile, the car weight of 2kg can be reduced. Generally, every 10% reduction in weight of car, the fuel consumption can be reduced by 6% to 8%. And reducing 100kg weight of vehicles, CO_2emissions can be decreased about 5g/km. Currently, CO_2Emission Standards draw up by the EU is about 230g/km. A typical aluminum parts can be reduced by 30% to 40% of the vehicle weight[6]. This paper uses Audi A8 as an example, because it uses the aluminum body. Audi A8 mass is 2075 kg, the average fuel consumption is 9.9L/100km and

Emissions are 199g/km. Since the body system is about 20%-30% of total vehicle weight, if using the steel body, the car mass is about 2500 kg. Based on the above information, we can compare the energy consumption and emissions using steel and aluminum body. (Tab 1)The calculation formula：

$$M_{al} = M_{st} * x * (1 - y) + M_{st} * z \tag{2}$$

$$E_{al} = \left(1 - \frac{M_{st} * x * y}{M_{st} * z} * i\right) * E_{st} \tag{3}$$

$$V_{al} = \left(V_{st} - \frac{M_{st} * x * y}{100}\right) * 5 \tag{4}$$

Where, Mal is mass of car with all aluminium body; M_{st} is mass of car with all steel body; E_{al} is average energy consumption of all aluminium body car; E_{st} is average energy consumption of all steel body car; Val is CO_2 emissions of all aluminium body car; V_{st} is CO_2 emissions of all steel body car; x is percent of aluminium in total vehicle; y is percent of aluminium in body structure; z is percent of steel.

Table 1. Comparison of Average energy consumption and CO_2 emissions

	All steel body	All aluminum body
Gross vehicle weight	2500kg	2075kg
Average energy consumption	11.8L/100km	9.9L/100km
CO_2 emissions	220g/km	199g/km

According to the above table, we find that reduction of energy consumption and CO_2 emissions is not obvious. We can calculate the energy consumption and CO_2 emissions in 100,000 km journey, because the operating life of the vehicle is more than 10 years at least so that 100,000 km is just a short distance. In addition, manufacturing process of aluminium previous works mentioned requires 50,000 km energy compensation and about 90,000 km emissions compensation [7]. We can find that the result is very worthy of recognition. (Fig.2)

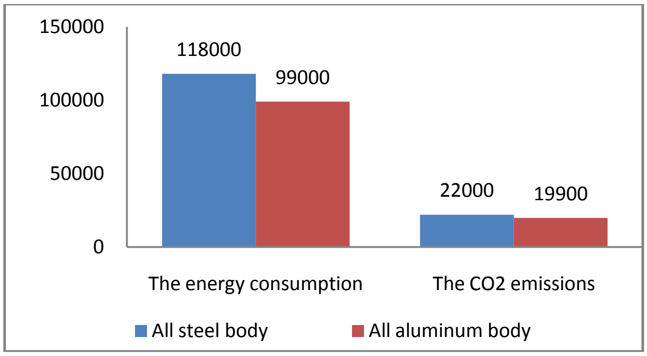

Fig. 2. Comparison of Average energy consumption and CO2 emissions in 100000km journey

4. Conclusion

Lightweight materials present a major opportunity for weight reduction and other benefits when used in place of mild steel and cast irons in automobile applications. This paper has shown with the aid of a few examples the possibilities that we now have for using materials other than steel in order to reduce vehicle weight. Furthermore many manufacturers are aware of the lightweight impact on energy saving and environmental protection. Although the aluminium alloy application in automobile body is extremely rare because of its high cost and complicated processing procedure. These methods must be improved for future vehicles in order to meet our high demands and specifications, whether self-imposed or laid down by law. With the development of technology, aluminium alloy will be large scale applications replaced of steel.

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